SCIENCE LECTURES

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FIRST AND SECOND SERIES.

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PREFACE TO THE FIRST SERIES.

THE courses of Evening "Science Lectures for the People," of which the verbatim reports appear in this little volume, were undertaken with the view of ascertaining whether the working men of Manchester appreciate the value of science instruction given in a plain but scientific form, and illustrated by experiments and diagrams adapted to large audiences. The movement has proved highly successful. Upwards of four thousand persons have attended the thirteen lectures delivered during the past winter. The class of persons present was chiefly that for whom the lectures were designed, and the marked attention and interest invariably shown by the audiences showed how keenly they appreciated the value of the information imparted by the lectures.

The subjects of the courses were as follows:—

I.—Four Lectures on ELEMENTARY CHEMISTRY. By Professor Roscoe, F.R.S.

II.—Four Lectures on ELEMENTARY ZOOLOGY. By Dr. T. Alcock.

III.—One Lecture on COAL. By Professor W. Stanley Jevons.

IV.—Four Lectures on ELEMENTARY PHYSIOLOGY. By Dr. John Edward Morgan.

The entrance charge of One Penny per lecture defrayed but a very small part of the heavy expenses of advertising, &c. The remainder has been kindly borne by several gentlemen interested in the scheme. The thanks of the lecturers are especially due to Mr. Pitman for his very accurate reports of their words.

H. E. R.

Manchester, February, 1867.

PREFACE TO THE SECOND SERIES.

I AM glad to be able to say that the Second Series of Science Lectures h[illegible] proved even more successful than the first; again showing that the people of Manchester value the opportunity of hearing the explanation of scientific tr[illegible]s from the lips of those who have made the extension of natural knowledge their chief occupation in life. The names of the lecturers will be a sufficient guarantee of the scientific spirit with which each subject is treated, whilst the eagerness with which the lectures have been attended proves that they were not pitched above the comprehension of those for whom they were specially designed. No fewer than 9,000 persons have attended the nine lectures given this winter, whilst the publication of the actual words of the lecturer for one penny has brought the subjects home to a much wider circle. The publisher informs me that editions of 10,000 of each of three of the lectures, and of from 5,000 to 8,000 of each of the others are already nearly sold out, whilst the demand for scientific literature of the kind is so largely increasing that a second reprint of the first series of lectures has been called for.

It is to be hoped that this example of Manchester may be followed by other large towns, for surely nothing can at the present time be more important than to infuse into the minds of the people an idea of that scientific truth which is rapidly being recognised as not only lying at the foundation of our material welfare, but also of our social and moral well-being.

To the various eminent men who delivered the lectures in this series, but especially to Mr. T. J. P. Joddrell, who generously defrayed the heavy expenses connected with these penny lectures, the thanks of the people of Manchester are due.

H. E ROSCOE.

March, 1871.

GENERAL INDEX.

FIRST SERIES.

GENERAL INDEX.

SECOND SERIES.

FOUR LECTURES

ON

ELEMENTARY CHEMISTRY.

LECTURE I.

INDESTRUCTIBILITY OF MATTER AND OF ENERGY.

IMPORTANCE of the spread of scientific knowledge amongst the people. Explanation of what happens when a candle burns—The matter of the candle is not lost or destroyed but exists in a different form. An examination of all chemical changes has shown that *matter is indestructible*. Value and use of the Chemical balance to determine the first great principle of modern science, that matter can neither be created nor destroyed. Second great principle of the *indestructibility of force or energy* only lately become known—In mechanics nothing can be done without an equivalent of labour or work—Wheel and Axle—Measure of mechanical force is the weight multiplied into the space through which it falls—Meaning of *foot-pound*—Impossibility of "perpetual motion." In the steam-engine the heat from the coals is used to do the work—Heat only a form of motion—When motion is stopped heat is given out; experiments to show this. Water boiled by friction. A fixed and definite quantity of heat can be got from a given amount of mechanical force, and vice versâ—The exact *mechanical equivalent of heat* was determined experimentally by Dr. Joule, of Manchester (1843-49)—He showed (1) that the quantity of heat obtained by any mechanical action is directly proportional to the amount of mechanical force expended (2) that by the fall of 772 lbs. through a space of one foot heat is always generated sufficient to raise the temperature of 1 lb. of water 1 degree Fahrenheit.

Professor Roscoe on coming forward was much applauded. He delivered his lecture in his happiest style, and made each point and illustrative experiment clear to every person present. His lecture will necessarily lose some of its force and freshness when put into matter-of-fact type, but we will endeavour to preserve the facts, as well as the simple language judiciously employed in their exemplification.

Mr. Chairman, my friends—(began the Professor)—Encouraged by the success of the experiment which was tried last spring—with the endeavour of imparting to you some portion of knowledge of science, and arousing some interest in scientific facts and reasonings, I have come again this autumn in the hope that we may have as successful a series of meetings as we had in the previous spring. I have been assisted most kindly by Dr. Alcock and Dr. Morgan who have volunteered courses on Natural History and on Physiology. These lectures will be given at a later period.

Although it may be necessary in Manchester to speak of the advantage of scientific reasoning, of the importance of scientific investigation, yet on the results of science it is almost needless for me to dwell. Let us only look at one of the real wonders of the world lately accomplished—the Atlantic Telegraph. How important for all of us, for every man and woman in England, to really understand something about the principles by means of which we are able to talk with our friends in New York! I might turn to a thousand other important applications of knowledge in the present day, in which you would find the same interest and the same necessity for a knowledge of the principles of science. And these principles are not so abstruse or so difficult but that they may be mastered by all who have the will to do it.

I wish to remark with regard to these lectures to begin with—that they are not intended to impart to you a full knowledge, or anything like a full knowledge, of the subjects with which we deal. I come here to bring before you some facts in elementary chemistry, and it is mainly for the purpose of interesting you in the subject that I thus come forward. It is not with the view of your learning so many things in the actual lectures which you may attend here, but with the view of your gaining interest enough in scientific matters to induce you to start and learn for yourselves, or to attend some class or other means of instruction by which you may work at the subject. Last spring, I am happy to say, a class was formed at the close of the lectures, for the study of chemistry, and upwards of fifty men attended that class, and a very successful class it was. The same thing will be tried this winter, so that

those of you who wish to attend a class will be able to do so. The class will meet in the adjoining room of this Hall, on Monday evenings at eight o'clock, and the terms will be two shillings and sixpence for a course of thirteen lessons, extending over a quarter of a year. I think there is little doubt that we shall be able to arrange for classes on other subjects should they be required.

I shall endeavour in what I have chosen for my subject to-night to be as plain as possible. The subject is not an easy or a familiar one, but one which may be understood if you will give me—as I am sure you will—your best attention.

I have undertaken to bring before you this evening, two of the most important general principles which lie at the bottom of all science. The first of these great laws is, that in all the changes which we see going on around us, and in all the changes which we can produce upon the materials of the earth which we see, feel, and handle, we cannot, whatever we do, either destroy or create matter; that material substances can only be changed in their properties, that they cannot be destroyed, that, in other words, *matter is indestructible.* This is the first great principle of modern science, and it is this which I wish first to make plain to you by explanation and experiment.

Let us ask ourselves in the first place what happens when a candle burns. Here we have a candle burning. If I allow that candle to burn for a few minutes it will burn down to my fingers, and the candle as such will have disappeared. Persons who are unacquainted with the great principle of the indestructibility of matter might say that here there was an evident loss of matter, for the candle does not exist any more. That this is not the case I am going to show you, for when the candle burns the matter of the candle is not lost, but it only undergoes a change in appearance, and the matter of the candle exists in this room just as much as it did before it was burnt. To prove this, I am going to burn this candle in this glass globe, into which I will first pour a little clear lime-water, which will remain clear until after the burning of the candle in the globe, when it becomes milky and turbid, showing that there is something in the air of the globe after burning the candle which was not there before. The candle will soon go out; but I will remove it before that occurs, in order not to have any smoke. The matter in this globe which was not there before the candle was burnt in it is the matter of which the candle was composed, and which, though it has disappeared from our sight exists in reality as much as it did before.

I can show you further a striking fact—namely, that if I collect all that which is formed by the burning of the candle, as I will

do for you, I shall be able to show that it actually weighs more than the candle did to begin with, for this simple reason, that in burning the candle we have obtained a chemical union of the component parts of the candle, with a substance contained in the air called *oxygen*. I can show you this by actually collecting the things formed when the candle burns, which made the lime-water milky, and which we call carbonic acid and water. This life-sustaining substance, called oxygen, exists in the air all around us, and we cannot live or breathe without it; and it is this oxygen uniting with the burning candle that forms carbonic acid and water.

[Dr. Roscoe burnt a small candle in a glass tube, for the purpose of illustrating this fact. The apparatus was suspended on a beam, which was in a state of equipoise before the ignition of the candle. As the candle burnt, the flame passed through a tube containing soda, which has the power of taking up the carbonic acid and water. To make the candle burn, air had to be sucked through the tube, which was done by means of a vessel of water at the back of the apparatus. At the close of the experiment, when the candle was consumed, that end of the beam was considerably heavier than before, and thus the fact was made plainly visible.]

Thus, you see, that really the candle after burning is heavier than before, that is to say, the materials weigh more, proving that there is no such thing as a loss of matter; neither can there be a gain of matter, for that is equally impossible; but we have an increase of weight, which is altogether due to the union of the component parts of the candle with the oxygen of the air, without which no candle can burn.

I may show you in another way, that when a body burns it is not lost. Here, for instance, is some of that most beautiful metal called magnesium. If I set fire to it, it will burn with a brilliant light, but here you see a white solid, magnesia, is produced by the union of metal with oxygen. This substance is formed by the union of the magnesium with the oxygen of the air, and there is no loss of matter when it is burnt.

Take this fact away with you, and try to master it, that there is no such thing in nature as a loss of matter.

I will show two other rather striking examples to prove the same thing. In the first place, I will show the combustion of a substance called phosphorus. The result is that a white body is produced, something like the result of the combustion of magnesium, the result of a chemical union of phosphorus with the oxygen. If we were to weigh this phosphorus and the oxygen, we should find

that these white fumes weighed exactly as much as the substances did before they were burnt.

I will show this in one more instance. You may think that if we exploded some gunpowder, that there, at any rate, we seem to have a loss of matter. The powder flashes away, and we see nothing remaining excepting a small quantity of smoke. Now, I will explode some powder here, and show that there is really some thing formed which was not there before, and that there has been no loss of matter. [The experiment resembled that with the candle and the lime-water.]

Now it is not by merely observing facts of this kind that the chemist has come to this conclusion; it is by making a great number of most accurate experiments, by means of what is termed a Chemical Balance, and by actually weighing everything whenever a chemical change occurs. In this way he has found that there is no such thing as a loss of matter, but that *matter is indestructible.* This has not been known for any great length of time. If you were to have asked anybody one hundred years ago, what became of a candle when it was burnt, no man living could have told you. It was thought that the candle was destroyed and lost. The man who first proved the indestructibility of matter by experiment and by using a balance was a Frenchman, named Lavoisier. I will now show you his picture in order that you may remember his name, and I will also show you a picture of the chemical balance, which is nothing but an accurate pair of scales, which weigh so accurately that a speck of dust is sufficient to turn the scale, and we therefore take care to shut it up inside a glass case. This is one of the most important instruments which the chemist has to use, and it is by the means of it that we have ascertained the truth of this great principle. Lavoisier, whose picture you now see, had an unfortunate end. He was guillotined at the time of the French revolution; some say because he was a scientific man, and others because he formerly had held the office of Farmer-general under the king.

We next pass on to the second part of our subject which is more difficult, but which I nevertheless hope to make plain to you. It is the second great principle in science, only ascertained within the last few years, namely, that just as *matter* is indestructible, so *energy* or *force is indestructible.* This requires a great deal of thinking about, and I want to try and make it plain by experiment as well as explanation. If I raise my hand and hit a man so as to knock him down, you would say there was a distinct creation of force. This is, however, not the case. This is no more a creation of force than there is a creation of matter when a plant grows.

You will perhaps not fully understand this at first, and in order to make the subject plain, I must begin at the beginning, so that we must first turn our attention to mechanical matters to see how we gain energy or force in mechanics. You will all admit, especially those who are of a mechanical turn, that in order to effect any work we must expend a certain amount of force. We cannot get force out of nothing. For instance, let us take the common mechanical powers. You will perhaps say that by the aid of a lever you can lift a ton by the action of your muscles, by which directly and unaided you would not be able to lift more than 100lbs., and in this way you may think there is a direct creation of force. This is however not the case, and I will endeavour to explain it. Supposing we take a wheel and axle, which is one of the common forms of the mechanical powers. You know that by this arrangement we can raise a large weight by means of a small one; that is, one pound on the wheel will lift for instance twelve pounds on the axle. You will see that we elevate twelve pounds with one pound, but you will at once observe that in order to raise the twelve pounds one inch, I must move the small weight twelve inches; so that in reality we do not *gain* any force by using such a machine, because in order to raise the twelve pound weight through one inch we have to raise the one pound weight through twelve inches. And thus we come to get a measure of mechanical force—namely, the weight raised multiplied by the space through which it is raised, and if we do this in the example in question we find that in both cases we get the same result, namely twelve. This product of the weight raised into the distance through which it is raised is called the "labouring force." Hence we see that by no mechanical arrangement can we gain force; what we gain in one way we must expend in some other way; and what we expend we shall in some other way gain. Otherwise it would be possible to obtain force out of nothing, to get what is termed "perpetual motion," a thing that will go without any expenditure of force, an idea which has long been given up as ludicrous. For years people have known that it is impossible by any mere mechanical means to get force without a corresponding expenditure of labour. In all the various machines you use, it is only a transference of force. Hundreds of examples will suggest themselves, particularly to those who are accustomed to work with machinery.

Let us now look at the case of the steam engine. How is its force generated? The piston is driven backwards and forwards in the cylinder by the steam, and after each stroke of the piston the

steam is condensed and returned again to the boiler. Very well, here we have got the water back into the boiler after the performance of a certain amount of labour by the piston, which seems to have done its work without having expended anything. What is it that is expended, and does the work in the steam-engine? Most of you will be able to answer this question. It is the *heat* which is expended, the heat which is derived from the coals under the boiler, that gives us the force; and you know that without continually shovelling in the coals your engine will very soon stop. Now, let us look at this question of heat a little more closely. What is heat? This is a point to which I wish you to pay especial attention. I want to show you that heat is nothing more than another form of motion, that heat is, in fact, the motion of the small pieces of which matter is made up; and I want you to understand that in order to get a certain amount of mechanical force, we must use a certain amount of heat. The more heat, the more mechanical force. If you have a steam-engine with only a small fire you will only get the steam up to perhaps a seven pounds' pressure; if you have a large fire you may get it up to fourteen or a hundred pounds, and you will work your engine proportionately quicker, the more heat you have. Heat, I say, is only a mode of motion. We can transfer heat into motion, as shown in the steam-engine. What is the railway train rushing along from Manchester to London but the heat of the coals transformed into the motion of the train, taking you to London in four-and-a-half hours. It is almost useless for me to show you an engine working. Anybody who lives in Manchester cannot help seeing engines working, and therefore they cannot help knowing that an engine is nothing but a machine for the conversion of heat into mechanical motion. I will show you a little toy which we have rigged up just to indicate this. Here we have the heat of two spirit lamps for heating the water in a flask which is our boiler. This is the oldest form of steam-engine, and as you see it spinning round you will remember that it is called Hero's engine, from the name of a philosopher who lived in Alexandria, I don't know how many years ago. Here, then, we have another illustration in proof of the fact that heat can be converted into motion, proving to you at the same time that the commonest things of life may teach us important lessons. Nothing is unimportant in science, and the most childish thing has often taught a lesson to the greatest philosopher.

Next let us take the proposition the other way about, and consider how we can convert motion into heat. You will all of you think of something by which motion is converted into heat. We

will adopt a very childish experiment which, I dare say, many schoolboys have tried—namely, rubbing a button on a form. If you do that, what happens? Why, it gets hot, and if I apply it to a bit of phosphorus, you perceive it sets it at once on fire.

Let me take one other example. I suppose you have all heard of the feat which I believe shows whether a man is a good blacksmith or not, that is hammering a piece of cold iron until it becomes red hot. I believe it can be done. I am not going to do it now, for I am not a good blacksmith, nor have I a hammer heavy enough, but I will hammer a piece of iron until it is so hot that it will ignite a piece of phosphorus. There you see the phosphorus burns, and here we have another illustration of the conversion of mechanical force into heat.

Again; wherever we stop mechanical motion, we always get heat. What do we see on the railway train? Why, a man carrying a box of grease to grease the wheels. What for? Because we want to get to London in four-and-a-half hours, and don't want the heat of the coals to come out again in the axles. We want the heat of the coals converted into motion, not into heat. If we stop that mechanical motion by putting on the breaks, we get heat evolved and often smoke and fire. I dare say you have all heard of the firing experiments at Shoeburyness, where they fire 600-pounders at great armour targets, costing, I don't know how much, and for which we shall have to pay; and if it teaches us something, perhaps the money will be well spent. One lesson we may learn from them is this, that the steel shot which is perfectly cold when flying through the air, gets burning hot by striking the target. Sir William Fairbairn tells us that he has actually seen a flash, owing to the great heat evolved the moment that sudden motion of the shot is stopped by striking the target.

I may show you a few more cases of turning motion into heat. I have not the means of firing a six hundred pounder in this room, nor would such an experiment be pleasant for you or myself. I cannot therefore show you a red-hot shot, but I can exemplify the result of a simple stoppage of motion. I have here an iron ball, and I am going to make it strike, not against a target costing thousands of pounds, but simply against an iron weight, upon which I have put some phosphorus, and the slight increase of temperature from striking the weight is sufficient to ignite the phosphorus. Whenever we clap or rub our hands, heat is evolved; and if I were to cover or rub my hands with phosphorus, every time I clapped my hands there would be an ignition of the phosphorus.

I have two other illustrations of the conversion of motion into heat. You all know I dare say of the old plan of getting a light in those countries where lucifer matches are unknown, namely, by rubbing two sticks together. The Indians adopt this plan of converting the mechanical motion of their hands into heat. I am not going to set wood on fire, but I have here a common fiddle-bow, and by working it forcibly between two pieces of wood, you see that I get some smoke. It is rather hard work to convert the mechanical motion of your arm into heat.

Some years ago there lived a very intelligent man of the name of Count Rumford, who was once busily employed in Munich, in Bavaria, boring some cannon by means of horse-power, and he found that the cannon got very hot. He put some water into the cannon, and observed the temperature of it, and he describes very naively in his writings how the water got hotter and hotter, and how at last, I think it was in 35 minutes, the water actually boiled; and he was very much astonished at the water boiling. He said, where can the heat come from by means of which the water is made to boil? and he rightly concluded that it really was the mechanical energy of the horse which was converted into heat. That was some years ago. Now I can boil water for you here instead of in 35 minutes in 35 seconds, by simply converting the mechanical force of a man's arm into heat. I have the means of turning round this tube quickly, and I put a thimbleful of water in the tube. You will be able to see that the water boils, because I will cork it up and make it blow the cork out. The motion has to be very quick, and there you have water boiled by friction.

I have still one other experiment to show how heat may be got from mechanical force. I have here a beautiful magneto-electric machine, kindly lent to me by the inventor, Mr. Wilde, of Manchester, and by the action of my arm I shall be able to melt this piece of iron wire.

The question would naturally arise, can we get from the motion of my arm any amount of heat, or do we always get the same amount of heat? In other words, do we by the expenditure of a given amount of mechanical force always get a given amount of heat? Now this is a question that requires experiment for its solution; we must ask a question of Nature by experiment, and if the question is rightly put, we need not fear but that the answer will be true and exact.

The experiments which decided this question are some of the most important ever made in science, and that is saying a great deal; and we in Manchester ought to be proud of the fact that

these experiments were made by a Manchester man. The name of Dr. Joule is far better known on the continent than it is in Manchester, as very often happens, in accordance with the old saying about prophets.* Dr. Joule set himself, so long ago as the year 1843, to determine this question experimentally—to get to know whether the heat evolved is or is not a definite amount; and if it is, as we should probably expect it would be from the definite character of the laws of nature, then how much heat can we get from a given amount of mechanical force; or, to put it the other way, how much mechanical motion do we need to expend in order to get a certain quantity of heat? Now this question is so important that we cannot at first understand its importance. I mean that it so implicates all modern science, because what is true of these two things is true of every other form of energy, whether it be electricity or chemical action, or those actions known as vital. Dr. Joule made a series of experiments extending over many years, surrounded by such great difficulties as are only known to those well acquainted with such investigations, and his name is therefore connected with the indestructibility of energy, as that of Lavoisier is with the indestructibility of matter. What did Dr. Joule do? He determined the amount of heat which was gained, when a certain definite amount of mechanical motion was used. Different persons would turn this handle at different speeds, and we must therefore measure it more accurately. This was done by means of a weight falling. Our measure of labouring force is, as I have said, a weight falling through a given space, multiplied by the space through which that weight has fallen. In this way Dr. Joule determined how much heat is given off when a given amount of mechanical force is expended. You will see a drawing below of the apparatus he used. I will show it on the screen.

[Professor Roscoe described the apparatus, which would not be readily understood without the aid of diagrams.]

Dr. Joule worked out the details of his experiments, though people did not understand what he was doing, and even now can scarcely appreciate the value of his labours, and ascertained with great care this important fact—that the quantity of heat produced by the friction of bodies, whether solid or liquid, is proportional to the force expended; that is, if you rub anything twice as hard, you get twice the heat. He thus determined this number, which

* The highest honour which the Royal Society can bestow has at length been awarded to Dr. Joule for these researches. He has received the Copley Medal for the year 1870 [H. E. R., Feb. 1871.]

is called the *mechanical equivalent of heat*. This tells us that if a weight of 772lbs. falls through a space of one foot, the amount of heat generated by that force is able to raise a pound of water through one degree of Fahrenheit's thermometer.

Let us then try to bear in mind these two ideas of the indestructibility of matter, and the indestructibility of force or energy, associated with the names of Lavoisier and Joule. If we recollect these two great principles of science, we shall get on very well in future. I will, in conclusion, illustrate the meaning and value of this principle by the steam-engine and a pound of coal. Just as we can determine what the amount of heat is which a certain amount of mechanical force will generate, so we can calculate what mechanical force can be generated by a certain amount of heat. This we can do simply from these numbers of Dr. Joule. We know the amount of heat evolved when this pound of coal burns. If we then calculate how much mechanical force can be generated by burning it, you will be perfectly astounded at the result. Put this pound of coal on the fire, and it will do a certain amount of work, and a certain number of pounds of coal will take you to London. How much force do you think there is pent up in this pound of coal? Let us look at it in this way. Supposing this were a spring, and I let it out at once, how high would it jump up? Why, it would spring to the height of 2,000 miles! The heat which is capable of being evolved by this amount of coal burning would raise a weight of 100 lbs. twenty miles high. That is what this pound of coal would do.

ELEMENTARY CHEMISTRY.

LECTURE II.

CHEMICAL COMBINATION.

ALL substances divided by the chemist into Elementary and Compound. Elements cannot be decomposed. Compound consists of two or more elements. List of most important elements. WATER is a compound of two gases, Oxygen and Hydrogen. If we throw a piece of the metal Potassium into water, the water is decomposed; the Oxygen combines with the Potassium, and the Hydrogen is set free, and burns. Sixteen parts by weight of Oxygen unite with two parts by weight of Hydrogen to form eighteen parts of water. Oxygen is sixteen times as heavy as Hydrogen: two volumes of Hydrogen combine with one volume of Oxygen to form two volumes of water-gas—Symbol H_2O. Oxygen and Hydrogen, mixed in the above proportions, explode violently when a light is brought to them. The heat evolved by these gases when they combine is enormous—shown by Oxy-hydrogen Blowpipe. Iron burns in this flame like tinder—When eight pounds of Oxygen combine with one pound of Hydrogen to form nine pounds of water, so much heat is evolved that when it is turned into mechanical action (see Lecture 1) it is able to raise twenty-one thousand tons one foot high. The same amount of force is needed to be expended in order to decompose the water—Water decomposed by the force of the human arm, by electrical and by chemical forces. Ice, water, and steam, or water-gas—Glaciers and Icebergs—Pure water—Rain water—Spring Water—Impurities in water—Necessity of care in the choice of drinking-water—Cholera and impure water—Manchester Town's water.

At the conclusion of our last lecture, the Chairman told you a story about Mr. Stephenson, to the effect that George Stephenson, when looking at the flame of a candle, said, "that light and that heat which the candle gives off are really the heat and light of the sun, which shone ages ago." Now that is true; but it is rather a difficult thing to understand. It is rather difficult to understand that we are here being illuminated by sun-light; we usually call it Manchester gas-light; but nevertheless it is sun-light and heat that shone perhaps millions of years ago. I will tell you another story of George Stephenson, which may help us to understand the first one. George Stephenson and a friend were once looking at a train which was rushing along; the trains in those days were not so common as they are now; and George asked his friend what he thought propelled or drove the train along. His friend answered, "Probably the arm of some stalwart, north-country driver." "No," said George, "It is the heat and light of the sun which shone millions of years ago, which has been bottled up in the coal all this time, and is now driving that train." What did he mean? Can we get an idea whether that extraordinary statement is true—that it is really the heat and light of the sun which is driving the train? I want to try and make that plain to you. What is the coal that we put under the steam-engine? I described to you last Wednesday the amount of heat and mechanical motion which we get from a pound of coal. I told you that a pound of coal, if we could convert the whole of the heat which it is capable of producing into mechanical power, would jump up two thousand miles high. Now where did that coal come from? What has that coal been? These are questions which we all may ask ourselves. The coal really was at one time a living plant; the coal, or the constituents of the coal, composed a living plant that grew in the bright sun-shine on the surface of this earth, not buried as it is now, below a thousand feet of rock, but living in and enjoying the bright sunshine, as the trees now-a-days do when the sun shines here. Well, how did these coal plants grow? They grew, as all plants only can grow, by the sun-shine. If we take away the sun-shine, plants cannot flourish. You cannot grow plants in a cellar, because there is no sunshine. Put plants in a window, and see how they creep up to the light; that is because the light is absolutely necessary for their growth; they cannot grow without the sun-light. So our coal plants could not grow without the sun-light. Remember it is the sun-light which enables it to take its food, namely, the carbon, from the air by decomposing the carbonic acid which the air contains. This it can only do by the help of the

sun-light. Now a certain definite amount of light and heat must shine upon the plant before it can gain one pound in weight; before one pound of the stem, or leaf, or branch of that plant can be formed. A certain definite amount of force, as light and heat, must shine upon the plant, and be used up in decomposing the carbonic acid of the air. What happens if we burn a plant? Why that definite amount of force as light and heat comes out again, and we get absolutely the same amount of heat out of a piece of coal when burnt as was necessarily used up years ago in order that that coal should be formed. Now I hope that you are able to get some idea of the truth of that statement of George Stephenson's, that the light and the heat of the sun which shone so many years ago, and was used up in the growth of the plant has lain hidden in the coal until it is burnt, when it again comes out and is rendered visible. It does not matter whether we burn the coal or the candle or the gas, for they are all the same thing—all were produced by the heat and light of the sun, and now when they return to their original form of carbonic acid, they give out exactly the same amount of force as light and heat as was originally needed to make them.

Let us now ask ourselves, "How do *we* live, each one of us, on this earth?" What is it that keeps us alive? Certainly, it is the food we eat. We, like the steam-engine, need fuel, though not coal, to be poured into us, in order that we may be able to live and act and move, to use our muscles and effect mechanical work. We must eat, and it is by the burning of this food in our bodies that we are enabled to exert mechanical force You may say, "It is a curious thing if we men are like candles, that we are actually undergoing combustion, that we are actually burning." Yet, nevertheless, such is the fact. I showed you in the former lecture what happened when a candle was burnt; I showed you that carbonic acid was formed, as was shown by the lime-water becoming milky; and now, if I show you the burning of a bit of charcoal in oxygen, you will see that the same thing goes on as when the candle was burnt. [Professor Roscoe set fire to a bit of charcoal in a glass globe filled with oxygen, and the result was a *sparkling* and very pretty example of combustion.] The same kind of action, as far as the chemistry of it is concerned, goes on inside our bodies. You may say, "We don't burn." It is true you do not see the same sparkling, but every person is hotter than the surrounding atmosphere, and the action which goes on is of the same kind; it is a combination of the carbon of the food in the body with the oxygen of the air, when carbonic acid is

formed, part of which in man and animals is converted into heat, and part into mechanical motion. Part of the dinner which I ate not very long ago is now being converted into muscular force, enabling me to talk to you in this large room; and therefore I am here actually converting heat into mechanical action, just exactly as the steam-engine does when it takes you to London. Every animal really acts in a similar manner to a steam-engine, but man is a much more perfect instrument than the steam-engine, and a man can get more mechanical force out of himself for the amount of food he consumes, and the amount of heat evolved by the consumption of that food than is possible in the case of the steam-engine. That I am really producing the same substance produced here by the burning of the charcoal, I can easily show you by a simple experiment. If I take this clear lime-water and blow into it, you will see it becomes milky. [Experiment.] Very well, I have blown enough air into the lime-water from my lungs to show that it is quite white. So that really an animal does the same thing as a machine, it converts heat into mechanical action.

You will now ask, I expect—"Whence do we derive this source of power?" We derive it immediately from our food. If we were not to eat we should not be able to effect this mechanical action; we should starve, become cold, and die. But let us ask ourselves, "Where does this store of energy in our food come from?" It comes ultimately from the sun, because we eat either animal food or vegetable food; we derive from that food the force which we need, and that food derives its pent-up energy from the sun, because no animals can live without vegetables; and in the second place, because no vegetables can live without the sun. It is the sun-light which keeps the vegetables alive, and it is by the destruction of vegetables that animals live. This is a subject which requires a great deal of thought, and probably more explanation than I can possibly give this evening. It is a matter which I might talk about through all the four lectures, instead of a part of one lecture, and very likely with a great deal of profit, but I could not help reverting, however briefly, to this subject, because it follows from what we said last time. So much then for the source of energy in animals and plants. Remember we are all children of the sun. If the sun had never shone, we, as we are now, could never have lived. (Applause.)

I am now going to tell you what chemistry teaches us about one of the commonest substances in nature, namely *water*. The object of the chemist is to find out all the properties of the substances he can get hold of: it does not matter whether the substance falls

down as a meteorite, perhaps from the moon, or whether that substance is got from the deepest mine; wherever got, the chemist's business is to examine it by experiment. Now in examining substances a chemist has to divide them into two classes—those from which he has been unable to get anything else, and those out of which he can get something else. These two classes of substances have been called by the chemist *Elementary* or simple substances, and *Compound* substances.

Here you see a list of a few of the most important elements—

(NON-METALS.)		(METALS.)
Oxygen	Arsenic	Lead
Hydrogen		Copper
Nitrogen		Iron
Carbon		Aluminium
Silicon		Calcium
Chlorine		Magnesium
Sulphur		Potassium
Phosphorus.		Sodium

Now water was long supposed to be an elementary substance; nobody thought that out of water they could get anything else but water; and in fact it was called one of the four elements. Fire, earth, air, and water were supposed to be the four elements by the ancients. That idea, however, has been entirely upset by chemists, who investigated this matter in an exact manner, and they found that water is really not an element, but is composed of two substances, which we term "gases," two substances like the air which surrounds us—invisible, colourless gases.

Let us begin at the beginning. Here I have got a small piece of metal termed potassium. Now this metal potassium will help us to answer the question—of what is water composed? If I throw a little bit of this metal into this basinful of water, you will see at once that a change takes place; that is to say, the metal swims about on the water, for it is lighter than water, and we have at once a flame, in fact, we can set the water on fire! Now what is it that goes on here? It is a very strange thing that throwing this on the water should produce this flame, and that the metal should swim about in this way. What is it that happens? I will tell you first what happens, and then I will prove to you that it is so. The water has been decomposed or split up into its two constituent parts, into the substances which on the one hand we call *Oxygen*—about which we had to talk a good deal last time—and into another substance which we call *Hydrogen*. It is this hydrogen and oxygen which, chemically combined, form water. Now

hydrogen is what you see burning; that flame which you see on the top of the water is due to this hydrogen, whilst the other component part of the water has united chemically with that metal to form a substance called "potash," which is a compound of oxygen with that metal potassium. I will show you that that is the case; and I will do it in a different way. I shall be able, I think, here to collect some of this hydrogen. Instead of allowing it to burn, I will catch it in a glass tube. You will then be able to see what sort of a thing this hydrogen is. I am going to plunge this metal under the water, and then we shall be able to catch the hydrogen. It cannot burn now, when I catch it in the tube, because it only takes fire when it comes into contact with the air. We have got half a tube full; that will be enough. We will now take it out, and we shall see that it is a gas that will burn when we bring a light to it. [The gas ignited, and burnt with a yellow flame.] That gas, then, is one of the component parts of water, and is called hydrogen gas.

We can in many other ways split up water; we can split it up, for instance, by electricity. I have got here an electric battery, and I can by means of the current of electricity split up this water. I have here two little tubes, and I have coloured the water blue in order that you may see it better. I am now going to pass a current of electricity through the water—the same kind of current exactly as that by which we send messages by the electric telegraph to our friends in New York. You will see that I can in this way collect the gases in these two tubes—in one I collect the hydrogen and in the other the oxygen. The electricity, as it were, tears asunder the particles of water into these two substances of which it is composed. The moment I join the wires and make the connection, that moment the bubbles of gas begin to rise. You see how beautifully we can show in this way the compound nature of water; how we can, as it were, boil it, and resolve it it into its component parts. It requires a great deal of force to do this; we cannot do it by muscular force alone; but I will try presently if I can tear the particles asunder with my hand, by the aid of Mr. Wilde's magneto-electric machine, by which I melted a piece of wire at our first lecture. But let us see, first, what we have got here. You will see that one of these tubes is quite full, whilst the other is only half full. This is a very important fact for you to remember. Here we find we have got twice as large a volume of one gas as we have of the other. Which is this gas of which we have the largest volume? Let us examine it; let us ask Nature this question, and find out which of the two it is. Let us

try whether it is oxygen or hydrogen, for it is surely one or the other. If it is hydrogen it will take fire and burn; if it is oxygen it will not take fire and burn. [A light was applied to the hydrogen tube, when it took fire.] Let us now try whether this is oxygen. You will remember the test we used for oxygen last time; it was that it re-kindled a bit of wood. Now here we have a taper which can be rekindled I dare say, if I blow it out and leave the wick red hot. [The taper was re-kindled more than once.] This demonstrates a most important fact; a fact so important that I have put it on the syllabus of the lecture for you to remember, namely, that two volumes of hydrogen combine with one of oxygen to form two volumes of water gas, or two volumes of steam. I cannot, I am sorry to say, show you that it forms two volumes of steam, that is too difficult an experiment to perform here, but you have seen that water contains one volume of oxygen and two of hydrogen. I will now try to show you the same thing on the screen by help of the lantern.

[Professor Roscoe succeeded perfectly in this demonstration, the bubbles of gas being distinctly seen bubbling apparently downwards on the canvas screen, and the current ceased when the connection of the wires was broken. The gas really bubbles upwards, being lighter than water, but in the image they appeared reversed. The electric wires were next attached to the Wilde's magneto-electric machine, and the same effect was produced in separating the oxygen and hydrogen, by means of the current of electricity, obtained when the handle of the machine was turned.]

Professor Roscoe proceeded to explain that just as in the burning of coal, we get the light and heat of the sun given off, so, he added, when I burn the oxygen, and hydrogen again, or when I bring the mixture near to a light, that moment I get heat evolved. Now that heat is very tremendous. The heat evolved by the oxygen and hydrogen when they combine, is so great that it is almost more intense than we can produce by any other means. I will show you how great that heat is, so great that I can burn very readily a bit of steel watch spring. And you know that when we have heat it would be easy to get from it mechanical action. I have here a small jet of hydrogen gas burning, and I am going to bring the oxygen to it. The purest water is here being produced by the chemical union of hydrogen and oxygen, and in that action such an enormous amount of heat is given off, that we can burn a piece of steel watch spring like tinder! [The steel was consumed in a few seconds in a brilliant shower of sparks.] That shows the enormous amount of heat given off. But I will show it

to you in another way. I am here separating water into its two constituent parts, and collecting the oxygen and hydrogen together in a small glass globe; just doing what you saw done on the screen. This is a very dangerous mixture. Nobody should mix hydrogen and oxygen in the proportion in which they exist in water in large vessels, because it is one of the most explosive substances we know. The explosion of this little bulb full will make a good deal of noise. Many lives have been lost from persons incautiously using this mixture. We have got our little bulb quite full now, so we will cork it up, and place two little wires inside to convey the electric spark, and then hang it up on this cord. I am now going to heat these two gases so that they may combine together, and so rapid is the electric flash that instantly I pronounce "three" and turn that handle, you will hear the explosion. You are aware that electricity passes so rapidly that it takes but the fraction of a second for a message to flash from England to America. [The explosion was loud and shattered the glass into a thousand pieces.] This is to show you the immense amount of force which is generated when hydrogen and oxygen are united, and therefore the immense amount of force which is needed to separate them. You may ask what is the amount of heat here evolved? Now I can tell you that, for it has been determined, and it is such an important point that I have had it printed on the syllabus. A certain definite amount of heat is evolved when 8lbs. of oxygen are combined with 1lb. of hydrogen, for that is the proportion *by weight* in which they combine. From water we get two cubic inches of hydrogen to one cubic inch of oxygen; but oxygen is sixteen times as heavy as hydrogen; and therefore when we weigh water, nine pounds are made up of eight of oxygen and one of hydrogen. Now if we burn eight pounds by weight of oxygen with one pound by weight of hydrogen, forming nine pounds of water, the heat evolved is so much that when it is turned into mechanical action (how heat can be turned into mechanical action, I tried to make plain to you on a former occasion), the heat is sufficient to raise 21,000 tons one foot high! That is the measure of mechanical force of weight raised through a given space. Hence you perceive what a tremendous amount of force is generated by this combination of oxygen and hydrogen.

I have shown you now how we decompose water, and how we can combine the elements of water, and also that when hydrogen burns it forms absolutely pure water.

Lastly, in the few minutes that are left, I will show you and tell you something about water. I suppose you all know that water

can exist in three different forms; it can exist as solid ice, it can exist as liquid water, and it can exist as gaseous or vapourised steam. Here in England we have not the opportunity, except in winter, of seeing ice in the solid form. Many persons have never seen ice in a solid form—those who live in tropical countries. But there are certain countries, not far from here, which can be reached in a day or two by the help of the steam-engine, where during the whole of the summer splendid examples of solid water may be seen, for instance in Switzerland, where there are snowy mountains with enormous masses of ice, termed glaciers. We may also see these masses of ice in Norway and other countries. In order that you may get an idea of what a glacier is like, I have got some beautiful photographs (kindly lent me by Mr. Dancer), which I will throw upon the screen. I will first show you a waterfall, one of those beauties of nature in which we have liquid waters. And then some of those wonderful masses of ice called glaciers.

Almost all the water found running on the earth's surface is more or less impure, and it is one part of the business of the chemist to tell us when water is impure, and also how to purify it. The best way to purify water is to distil it, though this cannot be done of course on a very large scale. For instance, here is some water which I have coloured blue, and by boiling it with a spirit-lamp, I shall get a colourless water dropping down this glass tube, and what remains will be impure water. This is the process which goes on in nature, and by which we get rain water; and if we collect the rain water in the country (not in Manchester), it is the purest of water you can get, because it has been purified by the great natural process of distillation, by which the water is carried up from the ocean into the air, through the agency of the sun, purified and precipitated again in the form of rain or snow, such as you saw on those beautiful mountains. In one or other of those forms water is constantly falling upon the earth, and every drop of running water, whether dirty as in the Irwell, or clear as in the Swiss streams, has been, in the form of rain, drawn from the ocean, condensed, and has fallen down again upon the earth in the form of rain water. When it has flowed a certain distance over the earth it becomes more or less impure, according to the nature of the ground over which it flows. If there are large towns near where it falls, or print-works, or dye-works, as in Manchester, so much the worse for the purity of the water.

It is a matter of the greatest consequence for every class of persons to be careful as to the water they drink. We, who live in Manchester, cannot be too thankful that those who undertake to

look after these matters for us—that is the corporation—have given us such a first-rate supply of water, for there is no city in England supplied with more wholesome water than Manchester. Now, this is a matter of vital consequence to every one of us; and this becomes more evident the older we grow, and the more progress we make in scientific knowledge. We have had lately a visitation of the cholera in England, and there have been two or three other visitations within our memory. The cholera appears to always come from the east. We know very little about it, but we are gradually getting to know more. There is, however, one thing which appears to be known with certainty about the cholera, and it is this, that it is brought on to a great extent, if not altogether, by drinking unwholesome water. This has been found to be the case not only in England but on the Continent; and wherever proper scientific investigations of the progress of the disease have been made, it has been almost invariably found that the cholera may be caused by drinking impure water.

When one of the last visitations of cholera occurred in England, I think it was in the year 1853, there was one place near Golden Square, in London, where the cholera was very bad indeed, and it was singular that the cholera cases were found in certain houses, whereas in certain other houses there were no cases of cholera. Afterwards this came to be investigated by competent persons, and it was found that in all those houses in which deaths from cholera had occurred, the people had drunk from a particular well near Golden Square, and that in the houses that were free from cholera, the people had used other water for drinking purposes. It appeared on investigation that the well water was very impure, and contained a great many matters which had filtered in from the sewage, organic matters which must accompany water when we get it from wells in large towns. Those persons who drank that impure water died, and those who did not drink it did not die. I do not say that cholera will always result from drinking bad water, but when the cholera prevails you may avoid the disease if you understand how, and you may take it if you do not take proper precautions, and one of these special precautions is to be careful as to what water you drink. This is only one case, but there have been hundreds of similar cases. In the visitation of the cholera this year in London, it was confined chiefly to those parts of London that were supplied with water by a particular company who stored their supplies in, or drew them from, an impure source; whilst those streets and houses that were supplied from another source did not suffer to a like extent. I repeat

therefore that we cannot be too thankful in Manchester that we have a supply of first-rate water, and none of us ought to drink anything but the purest town's water, which is collected, as you know, on the hills above Glossop, on that range of hills which separates Lancashire from Yorkshire. It is collected there in large lakes and distributed through mains and pipes all through our streets and into every house, so that we can draw the water as pure as if we were in the country, instead of using the impure well and pump water of our city, which becomes impregnated with all the dirt and abominations which collect in a large town. You will see from this that all the wells and pumps and springs in Manchester ought to be closed for drinking purposes, because it is exceedingly unhealthy to drink water of this kind. There are a good many of these pumps in Manchester, and perhaps those who draw water from them may not be aware of the great danger they incur, especially at such times as last summer when the cholera was about.

I have already exceeded my time, and I will therefore only say that here the dirty water is changed into colourless water, pure distilled water, which we have collected from our little still, and that in this way we are only doing what nature does on a large scale.

ELEMENTARY CHEMISTRY.

LECTURE III.

SULPHUR—SULPHURIC ACID—SODA—SOAP—BLEACHING.

SULPHUR found in Sicily in the native or pure state, also in combination with many metals—Sulphur burns in the air, forming Sulphurous Acid; 32 parts by weight of Sulphur combine with $2 \times 16 = 32$ parts by weight of Oxygen to form 64 parts of Sulphurous Acid—Symbol SO_2 Sulphurous Acid, Oxygen, and Water, combine together to form Sulphuric Acid, or Oil of Vitriol—Symbol $SO_4 . H_2$. Manufactured on large scale in leaden chambers—3,000 tons of Sulphuric Acid manufactured every week in South Lancashire. Process of manufacture described—Properties of Oil of Vitriol—strongest acid known—used in the manufacture of Soda—1,800 tons of Soda-ash made every week in this district. First, or Salt-cake, process: Common Salt (or Chloride of Sodium) and Sulphuric Acid yield Salt-cake, or Sulphate of Sodium, and Hydrochloric Acid. Second, or Black-ash, process: Salt-cake, Limestone, and Coal, yields Soda-ash (Carbonate of Soda) and waste. The production of Oil of Vitriol may be taken as a measure of the commercial activity of a district; the quantity of Soap consumed as a measure of its civilization. Chlorine and Bleaching Powder.

PROFESSOR ROSCOE began by saying: You will remember that at the last lecture I did not succeed in doing what I promised, namely, to fire a cartridge of gunpowder by means of electricity. We are going to try again to-night, and I think we shall succeed. The professor then joined the wires, which communicated with the cartridge at the other end of the room, and simultaneously with his signal the explosion took place. You will see, he continued, that the electricity did its work, and the previous failure

was not the fault of the electricity. Nature never makes mistakes; but *we* cannot at all times avoid them. On the previous occasion the wire was broken, and, therefore, the electricity could not pass, the roadway for it being intercepted.

I explained to you last Wednesday something about the chemistry of water. I propose to-night to take a totally different subject, and to tell you something about the chemistry of the substance which we know as sulphur, and which you all know, I dare say, as brimstone. Brimstone is sulphur, and sulphur belongs to that family of bodies to which we give the name of elementary substances.

Sulphur is found not chemically united with anything else. It is found in the neighbourhood of those wonderful and interesting places called volcanoes, and in volcanic districts generally, especially near Etna, in Sicily. From that source we derive the greatest part of the sulphur which we require in this country. But sulphur as it exists in these volcanic districts is mixed up with a great number of impurities, which must be got rid of before we can obtain pure sulphur. Part of this purification of sulphur is done in Sicily, and part of it is performed when it gets here. I have in my hand a lump of the sulphur as it comes into this country, before it is perfectly pure, and it is then a brownish yellow mass. Here is the sulphur after it has been completely purified in this country, and the difference is perceptible to every one. Now, I will show you a picture of the arrangement by which the sulphur is purified both before and after it reaches us.

Professor Roscoe then exhibited the pictures mentioned. The first showed the structure in which the sulphur was freed from the earth and rock which adhered to it. The sulphur was placed in a pot, round which a fire was made, which boiled the sulphur until the vapour passed into another pot, in which it was cooled, when liquid sulphur flowed out into tubs, the earth and other impurities remaining behind in the pots. The sulphur was rendered in this way nearly pure, but not sufficiently pure for our domestic and manufacturing purposes. When it was brought to England, therefore, it was again purified by another contrivance, which was exhibited. The sulphur was again boiled, and the vapour of the sulphur entered a large chamber, where it fell down in the form of the beautiful fine yellow powder known as flowers of sulphur. It fell like a soft shower of snow; in fact, flour of sulphur, or flowers of sulphur, were to sulphur what snow was to water or ice.

Now, this sulphur is a most important and a most interesting substance. In the first place, here we have some of the flour of

sulphur (showing it), and it looks like yellow flour—that is, it looks yellow by daylight. By gaslight it appears nearly white. If we burn a little of that beautiful metal magnesium, we shall get a brilliant light, which will show the true colour of this sulphur. [This was done.]

I have said that sulphur possesses some very important and interesting properties for us, and that from it we can obtain some of the most valuable substances for use in chemistry, in manufactures, in medicine, and in common life. The first thing we have to notice is, that when we heat the sulphur it takes fire and burns with a blue flame. [Experiment.] You all know the flame of burning sulphur, because you all use lucifer matches, and you know also the peculiar and disagreeable smell that is emitted. Now, as sulphur will burn in the air, you will be able to tell me that it will burn with greater brilliancy in oxygen. Here you have the sulphur burning in the air; now I will burn some in oxygen. The flame in the air is scarcely visible, only showing a blue lambent light; but in the oxygen it burns much more brightly.

Now let us ask ourselves what is the chemical change which takes place here, because that is our object. What takes place there is what takes place when a piece of charcoal burns in oxygen; it is a chemical combination of the substance burning with the oxygen of the air, and the substance which is formed here is called *sulphurous acid*, and it yields the unpleasant smell when you burn a lucifer match. That peculiar odour is not the smell of the sulphur, but is the smell of the body which is formed by union with oxygen—the sulphurous acid. Let us try to remember that. I have put it down in the syllabus:—"Sulphur burns in the air, forming Sulphurous Acid; 32 parts by weight of sulphur combine with $2 \times 16 = 32$ parts by weight of Oxygen to form 64 parts of Sulphurous Acid—Symbol SO_2".

Here again we come across the most important law in chemistry, namely, that all these substances which chemically combine together have a definite composition. We always find that 32 parts of sulphur combine with 32 parts of oxygen to form 64 parts of this sulphurous acid—this peculiarly unpleasant smelling substance which you perceive when you burn a lucifer match.

Sulphur will combine with a metal as well as with oxygen. I will show you that this is the case by combining some sulphur and some copper together. Sulphur is an elementary substance, and copper is an elementary substance, and when they combine a compound substance is produced called *sulphide of copper*. Sulphur occurs in nature not only in the free state in which you have seen

it here, but also combined with metals. For instance, the substances from which we get the metals are almost all chemical compounds of the metal with sulphur. Where do we get the copper from which our pennies are made, and which we see in a great many of the articles of daily use? It is found in the earth; but it is not found in the metallic state in which we use it, but combined with sulphur. Here we have the copper and sulphur combined together. [Experiment.] You see how hot the copper gets. It is now in a red glow; thus you see the chemical combination of the copper and the sulphur. The metal lead, of which bullets are made, is not found as such in the earth; it is found united with sulphur, and we must first get rid of the sulphur which is combined with the lead before we have the metal fit to use in covering houses, and for pipes, and the many other purposes for which lead is used.

Perhaps the most interesting, and certainly the most important, substance which we have to do with about sulphur, is the substance called *sulphuric acid*. Another name for this substance, which you will probably be all more or less acquainted with, is *oil of vitriol*. This oil of vitriol is got from sulphur. How is that accomplished? I may first tell you that this oil of vitriol is so important a substance that no less than three thousand tons of it are manufactured every week within thirty miles of the place where I am now standing! Three thousand tons per week of that is a large quantity. What is it all used for? What can we do with so much sulphuric acid? And how is this substance prepared, of which we use such an enormous quantity? These are the matters about which I propose to tell you a little this evening.

You are probably aware that Manchester is the centre of a district celebrated for its chemical trade. This chemical trade depends entirely upon sulphur. If there were no sulphur we could have no chemical trade of this kind near us, and it depends upon the manufacture of sulphuric acid, because that kind of acid is used for almost every chemical preparation. Whatever we have to make chemically we almost always have to use sulphuric acid in order to produce it. Not only, however, is it required for chemical purposes, but for ordinary uses of every day life. If we want to have our floors at home cleaned properly, what do we do? We send for a pennyworth of soda, and this soda cannot be made without sulphuric acid, and sulphuric acid cannot be made without sulphur. If we want to use soap to clean our hands, as we have need to do pretty often in Manchester, we must use soda to make

the soap, and in order to make the soda we must use sulphuric acid, and in order to make sulphuric acid we must use sulphur. I might go on enumerating a thousand common things, in the making of which we shall need to use sulphur; but perhaps these two will suffice. You can now understand, perhaps, how it is we manage in this district to get rid of 3,000 tons of sulphuric acid every week, because if we could not get rid of it, and if it did not pay to make it, you may depend upon it, it would not be made. Now then how do we make this sulphuric acid? In the first place we may make it either by burning sulphur itself, or by burning a substance which contains sulphur, and to which the name of sulphur ore has been given. This substance is called iron pyrites, and it is a compound of iron and sulphur, and when heated in the air the sulphur burns away. Supposing we make some sulphuric acid here from some sulphur. The sulphur we have is this beautiful yellow powder.

We must first of all burn the sulphur, and produce the substance called sulphurous acid. Now in order to make sulphuric acid, we have to bring the fumes from burning sulphur into a large chamber.

Everybody who has travelled by the railways about Manchester, cannot fail to have seen large leaden chambers, of which this is a model (model exhibited). You may see them about Newton Heath, St. Helen's, Widnes, on the way to Bolton, and in a great number of places about Manchester; and it is in these curious leaden chambers that the manufacture of this oil of vitriol goes on. I cannot make sulphuric acid in this model of mine, this small leaden house, but I will make it in a glass house, and it will then be more easily seen. For this purpose I must bring four things together. I must bring the sulphurous acid, which we got by burning sulphur: I must bring the oxygen of the air, I must bring steam, and I must bring the fumes from nitre. This bottle of sulphuric acid or oil of vitriol which I hold in my hand, is a thick oily liquid composed of sulphurous acid and oxygen of the air and water. It is very difficult for me to give you an exact description of what goes on inside this glass house, and I am afraid I must leave the full explanation of this for those who are really studying chemistry in the class which has been formed. But I think I can make it plain to all of you, that if we burn some sulphur here and bring some air to it, together with some steam and fumes from nitre, we shall be able to get some sulphuric acid, or oil of vitriol, in this glass house. First we will burn this sulphur inside the glass house. When well heated we bring the fumes

into the glass house, along with air and steam, and vapour from the nitre. [Professor Roscoe continued his explanations while developing the experiment, both to economise time, and fix the attention of his auditors.] Here you see we are getting our fumes, and shall soon have enough oil of vitriol. I can only manufacture a small quantity here, but, as I told you, the same process goes on in these leaden chambers on an enormous scale. In the meantime I can show you how we detect the presence of this oil of vitriol. If I put only one or two drops of this oil of vitriol into this large glass of water I can show you I have got oil of vitriol in that water, by pouring into it a little of this clear solution of a salt, called chloride of barium, the effect of which is to produce a white cloudy appearance, showing the presence of sulphuric acid. We will now try with what we have produced whether we can get the same kind of white cloud, and I think we most likely shall.

I have said that one of the most important uses of this oil of vitriol is to make soda or alkali; and those leaden chambers, some of which are as large as this hall, are always attached to these alkali works. In order to show you the importance of this branch of the chemical trade, I may tell you that the value of the materials manufactured in the alkali works of Great Britain amounts to £2,000,000 sterling per annum, and about one-half of this is manufactured within a radius of thirty miles from this place; that is, one-half of this trade is in South Lancashire, and the other half is round Newcastle-upon-Tyne, in Northumberland. I have on a diagram here a list of the chemical trades of South Lancashire for the year 1861, showing the very large quantities of various chemical substances which are made in our neighbourhood, and of these by far the most important is the making of sulphuric acid and the alkali trade. The following is a copy of the Table:—

STATISTICS OF THE LANCASHIRE CHEMICAL TRADE, 1861.

(1.)—ALKALI MANUFACTURE.

	Tons per week.
Common Salt (Na. Cl.) decomposed in the district ...	2600
Sulphuric Acid (Sp. gr. 1, 6) employed	3100
Soda Ash produced	1800
Salt-cake Soda	210
Bicarbonate of Soda..	225

	Tons per week
Soda Crystals	175
Caustic Alkali (Solid)	98
Bleaching Powder	155
Chlorate of Potash	5

(2.)—ACIDS.

Sulphuric Acid not used in alkali making	700
Nitric Acid	40
Oxalic Acid	8

(3.)—PRODUCTS USED BY DYERS AND CALICO-PRINTERS.

Dye-woods used for making wood extracts	200
Dye-woods used by Dyers	60
Garancine	100
Ammonia Alum	147
Proto Sulphate of Iron	80
Sulphate of Copper	28
Emerald Green	2
Protochloride of Tin	16
Nitrate of Lead	16
Stannate of Soda	10
Arseniate of Soda	10
Bichromate of Potash	14
Yellow Prussiate of Potash	5
	Cwt.
Red ditto	10
	Gals.
Red Liquor (Acetate of Alumina)	12000
Iron Liquor (Protoacetate of Iron)	5000
	Cwt.
Murexide	13
	Tons.
Gum and Gum substitutes	35
Starch	20
Purified Rosin	50

I have now, I believe, made a little oil of vitriol in our glass-house. We will pour a little water into the glass-house so as to wash out the gas, then shake it up, and see if we have not got a substance which will produce the milkiness which we saw before. I add a little of this clear solution of the salt, and we get the same white cloud, proving that we have manufactured on a small scale and in a few minutes some of this most important substance. (Applause.)

Now, this oil of vitriol is the strongest acid we know, and from it we can make all the other acids we need, as well as soda and alkali. I am going to-day to describe to you how alkali is made. I am afraid this lecture will be rather dry, but it is very important. (Further applause.) In the first place, in order to get the sulphuric acid as strong as we require it, we have to evaporate it as it comes weak out of the leaden chambers, that is, boil away the water which has been put in it. This boiling away of the water is done first of all in leaden pans; but after a time this acid gets so strong that it attacks and eats away the lead, and therefore the manufacturers have to use something else. Now you can imagine that if we had to evaporate a great many tons of this, we should have to use very large boilers. We cannot use iron boilers or leaden boilers. What are we to use? We must use either glass boilers, or boilers made of metal called platinum, which is so expensive that a boiler large enough for common use costs many thousand pounds; the other day I saw a very beautiful platinum boiler, which was exhibited at the British Association Meeting, at Nottingham, and that boiler was worth £6,000! Well, fortunately there is another substance without which we should be very badly off now-a-days, especially we chemists, and that is *glass*. What wonderful things we see now made of glass; there is a little glass bottle which will hold forty gallons (a laugh); in that kind of little bottle they boil down the acid. This specimen bottle has been kindly sent to me in order that you may all see what sort of bottles and boilers are used for boiling down sulphuric acid. It has been sent to me by Messrs. Percival and Yates, who I believe are the only makers in this district of these "small bottles." Five hundred weight of the acid is placed in the bottle. and the bottle put in an iron pot, with sand, and a fire is made underneath. When the acid is heated the water comes away, and the strong acid remains behind. If these bottles full of this sulphuric acid were to break, there would be a "serious matter," because sulphuric acid, when hot, is a most deleterious and corrosive substance, and forms a very hurtful vapour. But so well are these bottles made, and so accustomed are the workmen to handling them, that they do not often break them. These bottles are certainly extraordinary specimens of glass-blowing.

I have said that the sulphuric acid is used to a great extent for making alkali, and I am going to try to explain to you how alkali is made by the use of sulphuric acid. Near here we have a very large source of alkali, and that is the Cheshire salt beds. You know that in Cheshire there are enormous deposits of what is

called "rock salt." This rock salt consists of sodium or the metal of soda, united to a substance which I shall have to speak of, called chlorine—it is a compound of sodium and chlorine. This common salt, which we use every day at our dinners, is employed to produce alkali, and you will see by the table [on page 28] that 2,000 tons of salt are used every week in this district for making alkali. The first thing we have to do in order to make alkali is to add to it some of this sulphuric acid or oil of vitriol. What happens? I will pour some sulphuric acid on this common salt, and something very strange will take place. I must not use much, in order that we may not be incommoded by the result. Here we see an effervesence going on, and a substance is given off which fumes very sharply. What is this white smoke given off? I hold it above my head because I do not want to breathe it. This is the first process in making alkali, and it is called the *salt-cake process*. What happens here is that the sulphuric acid liberates from the salt a substance called hydro-chloric acid or spirits of salt, or muriatic acid, and leaves behind it the "salt-cake," as it is termed by the alkali makers. Now the hydro-chloric acid is not what is wanted. What we want is this salt-cake which remains behind, and the alkali makers were at first very much troubled with the hydro-chloric acid, which comes off, and did not know what to do with it. They found, to begin with, that when they let it go up their chimneys, the fumes were very annoying to their neighbours, and very destructive to their property, for it killed all the trees and plants, and destroyed every blade of grass; in fact, it ruined the farmers and gardeners in the neighbourhood. Then the manufacturers built tall chimneys, thinking that if they sent it up high into the air they would be rid of it. But there is no getting rid of these chemical bodies; you cannot destroy matter; and so, true to the law of nature, this acid came down again. But instead of falling on the farm next to the manufactory, it visited a farmer half-a-mile off, and destroyed his trees and his crops, and was as unpleasant to him as it had been to the nearer farmer. Then they thought of another plan. They turned all acid into the canals on the banks of which the works were built for the sake of cheap and easy transit. For this gas which you see coming off as fumes is taken up by the water with the greatest avidity. I hope to be able to show you that this is the case. [Professor Roscoe took a long tube filled with this gas, and on removing the cork from one end, the water rushed up violently, so quickly was the gas absorbed.] That shows why the manufacturers sent the gas into the canal; it was that the water might rid them of it. But the people who had

barges on the canals very soon complained, because they said all the iron rivets and nails came out of their boats. (Laughter.) Thus the chemical manufacturer was again in a difficulty. He did not know what to do with this disagreeable gas, which he could not help making in order to get what he wanted—the salt-cake. What was he to do? The answer will serve as an example to show how, by increasing our knowledge, we are able to make use of even deleterious and hurtful products. Instead of letting the gas go up the chimney, or sending it into the canal, the manufacturer collected the acid into a small quantity of water. The arrangement he adopted is illustrated in this model, and was first adopted by Mr. Gossage, of Widnes. He filled these towers with coke, and down the towers he let a stream of water trickle; at the bottom of the towers he admitted this hurtful hydro-chloric acid gas, and the falling water took up every trace of the acid, so that when the fumes came out of the top of the chimney, there was not the least trace of hydro-chloric acid gas left, while the water which had trickled down the towers was a valuable substance. It had taken up this gas and had formed a substance, which, so far from being a waste or injurious product, causing a loss to the manufacturer, became a source of wealth, and a product from which he could make other substances. This nuisance can, therefore, now be avoided; and in order to make the manufacturer careful, Lord Derby a few sessions ago, brought forward his Alkali Works Act, the object of which is to compel the manufacturers to collect all his hydro-chloric acid, and allow none of it to escape to the injury of his neighbours. A gentleman, well known in Manchester, Dr. Angus Smith, has been appointed as head inspector, and he goes round to see that the manufacturers do their duty—namely, condense every particle of this deleterious gas, so that none of it may escape into the air.

Having followed this hydro-chloric acid thus far, let us go back, if you please, for a moment, to the salt-cake, this white substance which is left behind, and which the alkali maker wants. This salt-cake is not alkali yet, it needs to be heated in a furnace with two other things—with coal and with limestone, in order to make it into alkali; it then forms a substance which the manufacturers term "black ash," which when dissolved in water yields the alkali. It would be impossible for me to describe to you minutely all the processes which go on in the enormous chemical trade of this district, or to do more than demonstrate the importance which sulphuric acid is to that trade. The sulphur which is used in making the sulphuric acid is still a waste product, and it would be

a great discovery if anybody could find out how to do without this sulphur, which is left behind in what is called the alkali maker's waste, and which smells very badly, and is a great nuisance. This is one of the nuisances which is not yet got rid of. I have explained to you how the nuisance of the hydro-chloric acid was got rid of; and in progress of time, and with the advance of science, I have no doubt we shall be able to turn this waste sulphur to as useful an end as the hydro-chloric acid. We must have patience; we cannot expect to get all these results at once.

Before I describe to you what they do with this hydro-chloric acid, I will show you the drawings of the furnaces in which these operations are conducted for making the alkali. [Professor Roscoe exhibited pictures of the leaden chamber in which sulphuric acid is made, and other furnaces in which salt-cake is made. The latter consisted of a large iron pan in the centre, holding several hundred weight of salt, upon which sulphuric acid is poured, and a great quantity of hydro-chloric acid is given off. Lastly, a picture was shown of the furnace in which soda ash is made, by mixing the salt-cake with coal and limestone.]

In the two or three minutes that are left, I will try to make it clear to you what the manufacturer does with this hydro-chloric acid which he used to throw away. Some of you may be old enough to remember the time when all the bleaching of calico in this district was performed by laying the cloth out on the ground to be exposed to the sun and the air; this was then the only way of bleaching known. Some years ago a chemical mode of bleaching was introduced, through the use of this hydro-chloric acid, from which is obtained the most powerful bleaching agent known, called chlorine gas—another of these elementary bodies of which I spoke to you. Here we have some of this chlorine gas. I will not make any of it here, because if I were to do so, it would prevent my speaking and very much inconvenience you, for it has a most powerful smell, and attacks the lungs with very great force, so that we have to be careful in using it. This chlorine gas is contained in this muriatic acid; I will burn this little bit of magnesium wire, and you will see that this gas is of a yellowish colour. It is a most powerful substance, and if I introduce a little metal it will take fire. [Professor Roscoe threw into the gas a little powdered antimony, when the metal took fire and burnt in the gas.] This is very extraordinary that the antimony should thus take fire.

Well, this chlorine also possesses most powerful bleaching properties, but it is singular that *dry* chlorine does not bleach. [An experiment demonstrated this. The dry chlorine had no

effect upon a piece of Turkey-red cloth, but when water was introduced the colour at once began to fade.] You will understand that the manufacturer does not want this substance in the gaseous form, but as a solid, so that he can pack it up in boxes and send it about to his customers. In order to effect this change, he sends the gas into lime. He has large chambers filled with common slacked lime, in combination with which the gas forms this white bleaching powder with which all of you will be familiar who have anything to do with bleaching. It is commonly, but erroneously, called "chemic" by bleachers, who have not as much knowledge of chemistry as is desirable. What does "chemic" mean? As if salt was not "chemic," and sulphur "chemic": as if this were the only "chemic" in the world. All things around us are "chemics," we ourselves are "chemics." (Laughter.) However, this goes by the name of "chemic," and if in the bleach-works you were to speak of chloride of lime, they would stare at you, but ask them "how is the chemic?" and they know very well what you mean. Well, this bleaching powder is got by bringing the gas into contact with lime, when the lime unites with it, making solid chlorine. For this substance the manufacturer gets £17 a ton, when thirty or forty years ago he sent the materials of which it is made into the air to the annoyance of his neighbours and the destruction of vegetation.

I will now show you how we can bleach by this powder. [Professor Roscoe mixed some of the powder with water, and in a few minutes bleached a piece of red cloth. He explained the process at the same time of what is called souring or liberating the chlorine by an acid. It was explained by the professor that this mode of bleaching was not applicable to the linen made in the North of Ireland and elsewhere, the fibre not being sufficiently strong to withstand the action of the acid. In conclusion Professor Roscoe stated that in his next lecture he should speak of coal and gas-making, and give another example of the extraordinary power of chemistry to turn hitherto useless products to a valuable purpose, as in the formation of beautiful colours from common gas-coal tar.]

ELEMENTARY CHEMISTRY.

LECTURE IV.

CARBON—COAL—FLAME.

CARBON mainly constitutes the bodies of plants and animals—without carbon there could be no life on the earth.—Carbon showed to be contained in sugar.—Carbon exists in three forms (1) diamond, (2) graphite or plumbago, (3) charcoal or coal.—Twelve pounds of each of these three modifications produce the same weight, or forty-four pounds of carbonic acid gas when burnt in the air or oxygen. Decolourising properties of charcoal—Use in sugar refining. COAL the remains of ancient vegetation—Explanation of changes which have occurred—Coal plants.—COAL GAS yields carbonic acid on burning—Contains marsh-gas or fire-damp, mixed with other gases—Causes of the explosions in coal-pits—choke-damp or after-damp is carbonic acid gas. Davy lamp—Explanation of—Experiments showing the value of—Olefiant gas contained in coal gas—Burns with luminous flame—Structure of a candle flame.

Vegetable and animal life—Dependence upon the coal for our national prosperity—Conclusion.

PROFESSOR ROSCOE, in commencing his fourth and concluding lecture, said, you will remember that in the last lecture I took for my subject Sulphur, and I endeavoured to show you some of the important chemical principles which are involved in that substance, and its compounds. We saw how the waste and deleterious hydro-chloric acid, which was at one time only a nuisance, was, by the progress of science, made available for most important economical uses, and instead of being a burden to the manufacturer, became to him a source of wealth, from the production of bleaching powder. This evening I propose to take another substance, but one not less important and interesting than the former ones. This substance also is an elementary body, the

name of which we have often had to mention, namely, *carbon* or *charcoal*. Now this carbon or coal is a substance of such great importance that we cannot at first realize its full value, for neither vegetable nor animal life could exist if we were to cut off this one substance, carbon; in other words, if carbon had not existed the animals and vegetables as they now exist could not have been formed, because all these things necessarily contain carbon. The first instance I will give you of the existence of charcoal in a vegetable shall be this beautiful white lump sugar, the product of the sugar cane refined. I shall be able to show you that sugar contains carbon by taking away the water from the sugar, for it is really a compound of carbon and water. I employ sulphuric acid—a substance I spoke about in the last lecture, to remove the water. This acid has the power of taking away from the sugar the water which it contains, and then we have the carbon left. I first add some hot water to the sugar to make a syrup, in order that the sulphuric acid may be able to act upon the sugar more expeditiously; and when the sugar is all dissolved, I will pour upon it some sulphuric acid, when we shall see the carbon. All our beautiful white sugar is now transformed into this boiling *black* substance. [This illustration, and all the subsequent ones, elicited the applause of the audience.] This shows you distinctly that a vegetable body such as white sugar contains carbon. Flesh meat also contains carbon. We know that when a piece of meat is over-roasted and burnt the black carbon comes out; and if I had done this with meat or blood, I should have produced the same black carbon.

I will show you this in another way. I will take this colourless liquid, which is turpentine, and show you that it contains carbon. If I moisten a piece of paper and put it into a jar, with a powerful substance which we noticed last time—chlorine gas—and if I introduce some of the turpentine into the chlorine gas, we shall see that it contains carbon, for a quantity of black smoke will be given off, and the paper will turn black, and even take fire. This blackening of the paper is caused by the carbon from the turpentine, and thus we see that in both of these white vegetable substances carbon is contained.

Carbon is found in nature in three distinct forms, so different one from the other, that we are not able to tell by the mere appearance that they are the same substance. What do you think when I tell you that the beautiful bright sparkling gem which we call the diamond is nothing more than this piece of coal, that is, chemically it is the same in substance, namely, carbon in its

purest form. Coal or charcoal is another form of carbon, and then we have that substance which we use to make black lead pencils, and for blacking grates, commonly and improperly called "blacklead," for there is no lead in it, or otherwise plumbago, or graphite. These things are nothing more than carbon, or diamond in another form, a form not so valuable, because it occurs in larger quantities, but perhaps even more useful than the diamond, though the diamond is a useful substance, because it is the hardest body we know of in the world; it is so hard that it will cut glass, and without it the glaziers would be in a difficulty. We cannot imagine things more different in appearance than blacklead, charcoal, and diamond, and yet these substances are actually one and the same—carbon.

Now, what happens when carbon burns? I showed you in the first of these lectures some charcoal burning in oxygen gas, and you would notice that a very bright sparkling took place; I need not, therefore, repeat that experiment, because you have seen it, and we have a number of others for to-night. What is it that happens here? Those who have attended these lectures, and attended to them—which is another thing—will know what happens when the carbon or charcoal burns; they will know that the beautiful bright sparkling is the result of the combination of carbon with the oxygen in the air, and that a substance is formed, the name of which I have written on the board—*carbonic acid;* and this carbonic acid is produced whenever substances containing carbon burn in the air or in oxygen; and it does not matter whether we burn diamond in oxygen or charcoal, or graphite in oxygen, the same thing takes place—namely, carbonic acid is formed. And what is more important, the same weight of carbonic acid is formed when we burn a certain weight of either diamond, charcoal, or graphite. If we were rich enough to burn 12lbs. of diamond, it would be a costly experiment, but the experiment has been performed with a smaller quantity,—how much carbonic acid should we get? Why, we should get exactly 44lb. I have put this down on the syllabus, because it is so important—"12lb. of diamond, charcoal, or graphite, would yield 44lbs. of carbonic acid." This is one of the reasons why chemists have come to the conclusion that these substances are one and the same, because they yield the same quantity of the like product; hence they must be the same substance.

A hundred years ago nobody knew that the diamond was the same as charcoal, and if any lady had been told that her diamonds were nothing but charcoal, she would have been incredulous. But diamonds are as valuable as ever they were, and perhaps more

valuable, because we cannot make diamonds artificially, though some day we may learn how; it is not an impossibility, all we have got to do is to find out how nature made diamonds, and then attempt to imitate her.

This carbon possesses many important qualities. In the first place, men are built up of carbon, and without carbon we could not exist. As I told you in the second lecture, the food we are constantly taking in is just the same to us as coal is to the steam engine. We burn this food-fuel, and the product of its combustion is carbonic acid, which is given off from the lungs. If we breathe through clear lime-water, you can make this fact palpable to sight. It is an important though simple experiment, and I have already shown you that the lime-water becomes milky-looking through the influence of the carbonic acid. This proves that we are really undergoing a process of combustion, that we are burning, and for every 12lb. of carbon we burn in our food, we produce 44lb. of carbonic acid, and for every given amount of carbon which we thus burn, we get a definite amount of heat and of mechanical action evolved.

Carbon is a very useful substance. One important property of carbon is, that it is capable in a certain form of taking away the colouring from substances, and it is therefore used in sugar refining. I may show you this. I have here some finely divided charcoal which is used in sugar refining. I will mix with this sugared water a few drops of indigo blue, and then if I put some of this charcoal into it, you will see that it has the power of taking away this blue colour. If I had taken some dark treacle it would have been discolourised by the carbon, and we should have had white treacle. This is the way that sugar is refined, a process that is carried on within a hundred yards of us, at Messrs. Fryer's works in Chester-street, where they use large quantities of this bone charcoal, simply for taking away the colouring matter which the sugar contains.

Perhaps the most interesting and important part of what I have to say to-night is in connection with *coal*. Coal is a form of carbon; carbon more or less pure. Now coal is such an important subject that I could have lectured upon it for the whole of the four evenings, instead of for a part of one lecture; but I thought it would be better to choose a wider range of subjects. Coal, I have said, is mainly carbon, but it contains some other things; it contains hydrogen, it contains oxygen, and it contains nitrogen.

Now, what is coal? or, what has coal been? These questions suggest themselves to everybody, and especially ought they to be considered by those who live in the midst of a coal field and a

coal-consuming district. What is all this carbon that is brought from a depth of perhaps several thousand feet below the level of the earth? If anybody will take the trouble to go down into some of our collieries, and will keep a sharp look-out with his lamp when he gets to the top of the level, he will probably see beautiful impressions of plants, some of which [showing them] have been kindly brought by a friend who was good enough to allow me to exhibit them this evening. You have observed on the floors as well as on the roofs of the coal seams, these impressions of leaves, plants, and even upright trunks of trees, which evidently were growing at the time of the coal formations. The coal is really the remains of an ancient vegetation which at one time flourished on the surface of the earth, and grew and luxuriated in the light of the sun, just as plants flourish now. I will show you on the screen magnified photographs of these plant impressions, of which you will see some splendid original specimens in the Peter Street Museum.

These pictures will show you what the plants are like. Some of them you will see were fern-like plants, bearing seeds, and botanists will tell you that these plants were reproduced in exactly the same way that such plants are propagated now. They were much the same kind of plants as the ferns and tropical growths of to-day, only larger. Here is one showing a section of the stem, which is almost like the section of a pine tree. Remember that these carbonized plants are found at a depth of perhaps 2,000 feet below the present level of the earth. Coal beds are in fact one mass of plants. You may say, "We don't find these plants and leaves in the coals in our coal-box." No, we only find them in certain parts of the coal field, because the whole of the plants have been so changed by being in the earth that they have become what is termed "bitumenized,"—that is, so altered by heat and pressure that the greater part has lost its vegetable structure. But in certain parts of every coal field we find these remarkable remains of fossil plants, leaving no doubt upon the mind of every person who observes them, that the whole mass of the coal consisted at one time of living plants.

These plants were once growing on the surface of the ground, but in the long lapse of ages the level of this ground has sunk; fresh deposits of sand and mud have been formed over the remains of these plants, and the mud and sand have gradually hardened to rock. I am well aware that to persons unaccustomed to consider geological facts it does seem amazing, indeed almost incredible, that such great changes have gone on, and are slowly but steadily going on, on the surface of this solid earth. Yet such is really

the case; no idea is more false than that the surface of our earth is fixed and unalterable; it is continually but very slowly changing at this moment, and such slow changes as these buried the coal plants thousands of feet deep in the earth.

Consider now for a moment the importance of coal to us in England. What should we do without our coal fields? What gives importance and wealth to the manufacturing districts of Lancashire, Yorkshire, Staffordshire, Newcastle, Scotland, and South Wales? How is it that we are able to make so much iron, and to produce all those manufactured articles which require for their preparation the expenditure of such an enormous amount of mechanical force? It is the coal that does it. Without coal these parts of England would be agricultural, just as Hampshire and Essex, and Kent are agricultural, because they have got no coal. Do you think the people of Essex or Hampshire would be content with 7s. or 8s. a week, or whatever they get, as agricultural labourers, if they could earn twice as much in manufactories? If they had the coal necessary in those counties, they would not be content with agriculture, but would start at once to manufacture something or other. But they have not the coal, and therefore the manufacturing districts are found in the coal counties. These districts depend entirely upon coal, and as soon as the coal is burnt out, Lancashire and Yorkshire, and the other manufacturing districts, will be ruined, and the inhabitants will have to go somewhere else. Hence the more you think of it, the more important will the coal question become; and you feel that everything here in Lancashire depends upon the coal, and if we had no coal fields neither should we have in Lancashire the cotton industry, or the chemical industry, or the iron industry, but we should have agricultural industry only. It is a matter, therefore, for grave and earnest inquiry—How long will the coal last? So important is this question, that a Royal commission has been appointed to report upon the question of the consumption of coal. A very interesting book upon this subject has been written by a friend of mine, Professor Jevons, of Owens College. You will find this important work in the Free Library, and it shows most clearly how dependent we are upon our coal, and Professor Jevons then discusses the question of how long will the coal last?

That diagram, which is suspended on the wall to my left hand, shows the relative produce of coal, and the area of the coal fields in various countries of the world. The diagram has been lent to me by Mr. Jevons. You will notice a large square of black at the top. That indicates the quantity of coal raised in Great Britain in one year—98 odd millions of tons. The other little

black squares, going down to the minute square at the bottom, indicate the quantities of coal raised in other countries; so that you see we are raising more than four times the quantity of coal that is raised in any other country, and certainly more than twice as much as every other country put together. Now it naturally occurs to any one who is accustomed to reckoning, as I suppose every Englishman is, to ask how much coal we have, and how long our coal will last when we are expending it at this rate. Of course, if a man has a certain number of shillings or pounds, and he spends them quickly, he will soon come to the end; while another man who has a great deal more money, and does not spend it so quickly, will find it last longer. Now look at the other side of that diagram, and you will see that the quantity of coal in the United States of America is enormously larger than the quantity contained in our own country, while the rate at which they are expending their coal is at present much less than the consumption of our own. We are burning ours at a great and rapidly increasing rate, and we have got but a small supply; whereas America does not yet consume at the same rate, and has a much larger supply. Of course nobody can say when our coal fields will be empty, but this much we know that the consumption is increasing at a rapid rate. We are raising and burning much more coal than we did ten years ago, and we shall go on increasing until the price of coal reaches a certain point, when our manufacturers will have to compete with others who get coal cheaper in America and elsewhere; so that, in a business point of view, it is a very serious matter to consider whether anything can be done to render that most unlucky time for England as distant as possible.

On the other diagram I have given you the actual area and number of tons of coal contained in England and in other countries, with a comparison of their ratios.

ESTIMATED AREAS OF COAL IN PRINCIPAL COUNTRIES.

	Square Miles of Coal.	Total.
United States	196,650	200,000
British North America	7,530	
Great Britian	5,400	8,964
France	984	
Belgium	510	
Rhenish Prussia	960	
Westphalia	380	
Bohemia	400	
Saxony	30	
Spain	200	
Russia	100	

ESTIMATED QUANTITIES OF COAL IN PRINCIPAL COUNTRIES.

	Average Thickness. No. Feet.	Tons.
Belgium	60	36,000,000,000
France	60	59,000,000,000
British Islands	35	190,000,000,000
Pennsylvania	25	316,400,000,000
Great Appalachian Coalfield	25	1,387,500,000,000
Indiana, Illinois, Western Kentucky	25	1,277,500,000,000
Missouri, and Arkansas Basin	10	739,000,000,000
North America (assumed thickness over an area of 200,000 square miles.)	20	4,000,000,000,000

RATIOS OF ESTIMATED QUANTITIES OF COAL.

Amount of coal in

Belgium, 36,000,000,000 tons	1
France less than	2
British Islands, rather more than	5
Pennsylvania, a little less than	9
Appalachian, about	38½
Indiana, Illinois, Western Kentucky	35½
Missouri and Arkansas	20½
Entire Coalfields of North America	111
,, all Europe	8½

Taking the quantity of coal in Belgium as 1, you will see that in the British Islands we have rather more than 5, whereas in the one single coal field of the United States, called the Appalachian coal field, the quantity is 38½ times as much as in Belgium, and the entire coal fields of North America contain 111 times as much, while all Europe has but 8½ times as much. So that you see how little coal we have in Europe, and how fast we consume it; and how much coal they have in America, and how comparatively slow they are spending it.

Another very important use of coal is to make coal gas. Here we have an apparatus at work for making coal gas, and you see we are burning the gas we have manufactured. This process of coal gas making is one of great importance to us, more particularly in the winter, and we all felt much inconvenience, I did for one, on being deprived of gas in my laboratory when the men in the gas works struck. The gas is made by putting the coal into an iron or brick receptacle called a "retort," where the coal is heated. If the coal were nothing but pure carbon, we should get no gas out of it; but the most suitable qualities of coal for making gas, such as the Wigan cannel, contains, as I have said, other substances, namely, hydrogen, oxygen, and nitrogen, and these sub-

stances help to yield the gas. The jet of gas which we are making here will probably burn throughout the evening. You see it burns steadily and brightly, and it seems to be of rather a better quality than even the excellent Manchester gas. Our little retort holds about a couple of pounds of cannel coal, those in the public gas works would hold many tons. The gas passes from the retort into the tar well, where the tar is deposited, thence into the atmospheric condensers, and the lime purifier, and then into the gasometer, where it is stored up for use. [In order to illustrate the process of gas making more fully, Professor Roscoe exhibited a picture of a gas manufactory.] One of the substances, from which the gas has to be purified is tar, another is called ammonia, and another is water. Gas-tar was once a waste product, but it has of late years become useful and valuable. What do you think we make from gas-tar now? Why, we make those splendid colours which the ladies, and no doubt the gentlemen, so much admire,—the mauves and magentas, as well as greens, blues, violets, and blacks. Not only are brilliant colours made from gas-tar, but actually perfumes, as well as essences for flavouring cheap confectionery, such as essence of bitter almonds, fruit essences, &c.

Coal-gas is not a simple chemical substance, it is a mixture of a variety of bodies, some of which are wanted, and some are not wanted. One of those which is not wanted is called carbonic acid, and another which has to be got rid of is sulphuretted hydrogen, the substance which smells so peculiarly and disagreeably in rotten eggs. To get rid of these things the gas is passed through lime. There is another substance in the gas, which is also found in coal mines, and is there called "fire damp," not that it is damp, or has anything to do with water. "Damp" is a word of German origin, and means air or gas. This fire-air or fire-damp sometimes explodes in the coal measures with fearful and fatal violence. It is, therefore, important to understand its nature, especially in a district where these accidents are only too common. It is very important that everybody, and especially those who work in coal mines, should be acquainted with the few scientific principles upon which the explosive nature of the fire-damp depends. If you go into a coal mine and ask the men if there is any fire-damp in the mine, they would not know what you meant; but they would say there was some "sulphur" up in a corner somewhere. They call the fire-damp sulphur, but there is no sulphur in it, it is nothing but carbon and hydrogen; they give it the name of sulphur because it burns with a bluish flame. This shows how ignorant the miners are of chemical science, and accidents

often happen from the want of this scientific knowledge. What is the cause of these explosions in coal mines? It is simply this, that the coal-gas or fire-damp gets mixed with air, and it then forms an explosive gas. That this is the case I can easily show you. I will make a small explosion of coal-gas, because coal-gas and fire-damp are nearly of the same composition. When carbon is burnt, carbonic acid is produced; therefore you will have no difficulty in seeing that when this coal-gas is burnt in air, carbonic acid must be produced. You will remember, I am sure, the effects of this acid upon the unfortunate miner. The men who are in the mine when an explosion occurs from fire-damp, even if they escape being burnt to death by the fire, are almost sure to be suffocated by the "choke-damp," or carbonic acid gas, which is produced by the burning of the carbon of the coal gas or fire-damp. I will show you first that we can get an explosion when we mix a little gas with air. [The gas exploded harmlessly in the open glass vessel] Professor Roscoe then introduced a lighted candle into the vessel, and the light was soon extinguished. Like the flame of the candle, the life-flame of the miner goes out in this deadly gas. [A bladder filled with the explosive mixture was then fired by the electric spark; the explosion was like the noise of a cannon, and of course the bladder was blown into ribands.]

There is one other important thing to be noticed, and that is the Davy safety-lamp. What is the principle upon which Sir Humphrey Davy made his lamp, so as to enable the men to go with safety into the most explosive gas? The principle is a very simple one; it is that flame cannot pass through a common piece of wire gauze. Here we have a piece of ordinary wire gauze, such as is used for making wire blinds, and you see that the flame cannot pass through it. Now, imagine this bound round, with a lamp inside, and that is the Davy safety-lamp (exhibiting one). The light burns inside the lamp, the gauze being no obstacle to the ingress of the air, but the flame cannot pass through, and the temperature is not sufficiently high on the outside to ignite any explosive mixture. Let me show you that this is the case. I will insert this lamp into some vapour of ether, which is very inflammable, but it does not ignite, whereas the moment I insert a bit of lighted paper into the ether it takes fire and burns with a large flame. No doubt this safety-lamp invented by Sir Humphrey Davy has saved a great number of lives, and would save more if the colliers were more careful, but they become negligent from being exposed to danger daily. Sometimes a collier will unscrew the top of his lamp in order to light his pipe, and the consequence

is that not only is the unfortunate man himself killed, but he is the cause of the death of many others. In many mines the Davy lamps are padlocked, so that the miners cannot unscrew the top. Then they sometimes take lucifer matches down, and on striking one of them for the same purpose, there may be another dreadful explosion. The force of this gas I have shown you by an experiment; but imagine this room, or a space twenty times as large, filled with the same explosive gas, and you may form some idea of the tremendous force of these most terrific explosions.

There is only one other subject I want to speak about, and that is the beautiful colours derived from coal-tar. There is in the tar a singular and important substance to which chemists have given the name of "benzole," from which, after repeated experiments, these splendid colours have been obtained. I will show you the formation of one of these fine colours in this vase of water. I have here some of the substances from which these colours are made,—two colourless liquids, and if I pour a few drops of each into the vase of water, you will see what a powerful colour will be imparted to the water in a few minutes. I can make it as dark as I please. This is the colour called "magenta," which is valuable for dyeing purposes. I can also dye this piece of wool with the magenta colour. Thus, then, we have a second example of the use to which these waste products are converted by the aid of science. From hydro-chloric acid we get bleaching powder, to make our calicoes white; and from coal-tar we get these splendid colours for dyeing our calicoes, woollens, and silks.

In conclusion, I have only to say that I have been much pleased with the attention of my audiences, and I hope that the facts and illustrations which I have brought forward will have induced in your minds an interest in the science of chemistry, and a desire to pursue its study further. I have to state that Dr. Alcock will say a few words about his lectures on Zoology which he has kindly undertaken to deliver here, commencing on Wednesday next.

Dr. Alcock said he was sure they all regretted that Professor Roscoe's Lectures were finished. They must have learnt from them a great many facts in illustration of the laws of nature and the application of them to scientific purposes. Professor Roscoe had given them in a simple manner those illustrations of the advancement of science which would have been gladly received by the wisest men of any past age, but they were beyond their reach. In this age science was within the reach of everyone. It would be a disadvantage to him to follow Professor Roscoe, but he

should do his best to interest his auditors. His subject would be Zoology, or a knowledge of the animal kingdom. Four lectures would be given, one being devoted to each of four plans upon which animals were formed; and these four plans would lead to a comprehension of the fifth plan, after which man himself was made. These lectures would also lead to a better understanding of Dr. Morgan's lectures on Physiology, which were to follow. Dr. Alcock added that his first lecture would be about animals, that were made of nothing but soft jelly, and had no organ of any kind, and he should show what they did, what they were like, and how great was their influence in the world.

On the motion of a Working-man, who said he had come a considerable distance to attend these lectures, thanks were most cordially voted to Professor Roscoe for the pains he had taken in elucidating the science of chemistry, and the pleasing manner in which he had imparted his knowledge.

PROFESSOR ROSCOE, in reply, said he was rewarded by their attention, and by the manifest interest which had been created in the study of the science to which he devoted himself.

ZOOLOGY,

OR

FOUR PLANS OF ANIMAL CREATION.

LECTURE I.

FIRST PLAN.—JELLY-LIKE ANIMALS.—LIFE WITHOUT ORGANS.

INTRODUCTION. — General view of the mineral world; nature of mineral substances. Water and air the two elements in which living beings can exist.—No life without water. Living beings are either Plants or Animals. Nature of living beings—what they are made of, and how they differ from lifeless mineral substances. Characters of a Plant. Characters of an Animal.

Several plans of the Animal Creation. First Plan.—Body of the Animal made of nothing but soft jelly. Examples of such animals, Amœba or Proteus Animalcule, Actinophrys or Sun Animalcule, both common in ponds and ditches; description of each, habits of life; feeding, without mouth or stomach; digestion of the food. Foraminifera are sea creatures of a similar kind but covered with a shell. Description of the animal and its shell; meaning of the name Foraminifera. Endless variety of beautiful forms. Growth and manner of formation and chemical composition of the shell. Countless multitudes of them—the sand of the sea-shore, in some places, little else besides their empty shells. Bed of the ocean covered with them in many parts to a great depth. Chalk rocks composed of them. Great effects produced by what appear at first sight trifling causes. Nothing insignificant in Nature. Sponges, the soft living part and the skeleton. Many kinds differing in the structure of the skeleton—Commercial sponge. Other kinds not fit for household use. Infusoria or Water

Animalcules ; meaning of the name. Stagnant water full of them. Description. Many kinds. Bell Animalcule. Trumpet Animalcule. Use of these creatures in the economy of Nature. Life without organs. What is meant by organisation ? Life a cause of organisation, but not a consequence of it.

DR. ALCOCK said, My friends, if a man ever finds time to look up from his work, he may see that there is around him a wonderful creation, in every part of which there is motion and change, and every change is an advance towards something more perfect. These changes take place with such order and regularity, that most people do not see that anything is happening; it is only when you look closely into nature that you find all is activity, and there is nothing like stagnation anywhere. You had illustrations given in the lectures by Professor Roscoe that these changes which are always going on occur in perfect order, so that under the same circumstances the same thing always happens, and this is so strictly the case that they are said to be illustrations of natural law. Now these natural laws are of the greatest importance for us to understand. I am sure that you believe this so far as chemistry is concerned, for you have seen that we are able to make substances of great commercial value by taking advantage of these laws, and that the want of full knowledge of them may cause people to suffer greatly from injurious things, as from waste hydro-chloric acid, until it was got rid of in the formation of bleaching powders. I merely mention this to show that you are already acquainted with the importance of a knowledge of natural law. With regard to life in connection with external circumstances, I shall not be able to show you so clearly the importance of a knowledge of the laws regulating these things; but I think I can convince you of their importance by simply telling you what you know very well,—that your life and health are the most valuable things you possess; anything, therefore, which will assist you to understand the laws which govern life and health in connection with external circumstances must be of the greatest value.

Supposing a man becomes alive to what is going on around him, he will take a wide and extended view of this world upon which we are placed, and will see that it is a great round mass of

solid substance hanging free in the heavens; and, if seen from a distance, shining like a star. I will show you upon the screen a photograph of the moon, which will give you an idea of what will be the appearance of our earth if seen through a telescope from some other planet. I show you the moon, because with every desire to satisfy me and you, Mr. Brothers was not able to fix his camera upon any place where he could photograph the earth. You will see it is a great round ball of solid substance, made uneven by mountains and valleys. If it were the earth we should have upon it, in addition, a great body of water, forming our oceans and seas, and above that there would be a layer of gaseous matter, which we call the air or atmosphere. We have on our earth, then, illustrations on a large scale of the three states in which material substances can exist, namely, the solid, the liquid, and the gaseous state. Now, though I cannot show you a true portrait of the earth, I will give you a picture of its shadow from which you may see that it is really globular. I will show you a photograph of an eclipse of the moon where the shadow of the earth cuts off a portion of the full moon, and this shadow, as you may see, is cast by a round body.

Let us now consider the solid material of the earth for a moment. The solid substance of which the earth is formed has a very uneven surface; in some places it rises high into mountains, and in others there are deep hollows. You have here represented a portion of the earth's surface, taken from Shetland, a bleak, inclement sort of place. This is an example of the solid crust of the earth, without anything further; it is what I may call the bare bones of the earth, consisting of rock, and this is the floor upon which all living things have to exist. We should bear in mind that there are many arrangements in connection with the earth, taken as a whole, which are essential to the existence of living beings. In the first place the earth turns round the sun once a year, and in that way gets that regular and constant supply of light and heat which is necessary to all life. Then the earth turns round upon its own centre once in twenty-four hours, giving us the alternations of day and night, an arrangement equally necessary for life and health. Then again there is one thing in the position of the earth which you will have noticed, it is that the axis upon which it turns, instead of being upright, slants a little; you might almost suppose it happened by chance, but it is that slanting of the axis of the earth which gives us the varied seasons of the year, and in all probability the very existence of life upon the earth; for if the earth were perpendicular, all the central parts would get roasted by the

sun's heat, and be intolerably hot, while the remainder would be eternally frozen and unbearably cold. The probability, is, then that if the earth instead of being tilted was straight up, there would not be a living thing upon its surface.

I have told you there is a great deal of water upon the earth, in the oceans which occupy so large a part of its surface. But the water does not remain in the sea. I told you that there is a gaseous atmosphere surrounding the earth, and it is a property of water that it is continually rising into this atmosphere, and saturating the air until it collects in the form of drops, through being made colder in the upper regions, when it falls down in showers, keeping the whole of the earth's surface moist. I show you here a view of glaciers in the Alps. You see at the tops of those mountains what enormous masses there are of frozen water, every particle of which has been conveyed up in a state of vapour into the higher regions of the air, and has then fallen in the shape of snow. In most cases when the cold is not so great, the water runs down in streams and rivers, fertilizing the earth's surface, and making it possible for things to live upon the land. Now water and air form the two elements in which living things can exist. Water is essential to all life; and even those animals and plants which live upon dry land, as we call it, still depend upon water for their existence. They derive all their food either directly or indirectly from substances which are naturally dissolved in water, and their bodies are built up in water; so that even the driest looking creatures are always saturated with it.

Living things are either plants or animals, and I shall have to tell you how to distinguish between the two.

This picture represent a plant and an animal—it is a bull standing under an oak tree—and you can readily tell which is the plant and which is the animal; but those who have studied this matter most closely, have found great difficulty sometimes in clearly distinguishing plants from animals; not, of course, in such a case as this, but when their characters are of a much more indefinite nature. I shall show you now a water object, arachnoidiscus, and you will see what the nature of this difficulty is, for you will be unable to say whether it is plant or animal. The distinction between a bull and an oak is clear enough, and if I had to tell you in what they differ, I might say that the bull contains a quantity of muscle and nerve substance, and that the tree does not; no vegetable contains muscle and nerve; but then a great many animals that are low in the scale are equally without them. This water object is a living thing, and it will serve to illustrate

the characters by which living things, whether animal or vegetable, are distinguished from mineral substances. It springs from a germ which requires parents similar to itself for its production, and that germ has the power of unfolding, and at the same time enlarging and drawing into itself materials from outside, and building them up into the form peculiar to itself. Every living thing is composed of three or four gaseous elements—carbon, oxygen, hydrogen, and nitrogen; sometimes the nitrogen is omitted. To these a few other substances are often added, such as salts of lime, soda, potash, and small quantities of sulphur and phosphorus. Living things exist only for a time, during which they pass through a set of progressive changes; they grow till they reach their full size and perfection; then their powers begin to decline, and at last they die, and the materials of their bodies disperse; but before this happens they produce germs, which grow into new living forms like themselves.

Now for the distinction between a plant and an animal. Plants derive all the materials of which they are composed from the mineral world, and take it in by their roots and their general surface in a state of solution. The food of plants is carbonic acid, ammonia, and water. Plants continue to grow as long as they live, for they are constantly adding new material to their substance, while most of that which is once deposited is retained. The duty of plants is to convert mineral matter into compounds, suitable for the food of animals, and to store it up for their use. The chief part of their substance is composed of compounds of carbon, hydrogen, and oxygen united together. Animals have all parts of their body sensitive, and capable of contraction and movement, every part is constantly active, and this activity causes waste of all the structures of the body, which require to be continually repaired by fresh material. Animals grow only for a certain time, after which, though they continue to take in food, all of it goes to replace wasted and worn-out material. The food of animals always consists of substances which have been already compounded as parts of living bodies, either animal or vegetable, and it is received into the interior of the body through an opening on the surface. It is then digested and conveyed to all parts to nourish them.

The composition of animal bodies is carbon, oxygen, hydrogen, and nitrogen, four elements combined together; whereas there are only three in plants generally speaking. The surface of the bodies, of animals is also sensitive, so that they can feel external impressions, and often they have, in addition, the senses of sight, hearing,

and taste, but not always. Those are the distinctions between plants and animals.

I intend in these lectures to give you a description of four of the plans upon which animals are formed. The first is the one I shall speak of to-night; it is a plan without a plan, for the body in this case is a mere mass of jelly without any structure or form in it. The second plan, which I shall speak of next week, is the radiate plan, as you see it in the common star fish. You have this plan architecturally in the model prison, with the governor's house in the centre, and the wards branching out like rays. The third plan is the locomotive plan, which you may compare with a railway train, consisting of a number of similar pieces set end to end in a row, as in a worm or a centipede. The fourth and last plan is what we may call the soup-kitchen plan, such as you have in the mollusca or shellfish, where the digestive and secreting organs take the first place, and everything else is made of secondary importance.

To-night I have to explain the jelly plan, where there is no distinct plan at all; but life is contained in something that is almost without form. The body of the animal in this case is nothing but a little spot of soft jelly, and might be compared to a drop of thin gum water. You have plenty of examples of such animals, and I shall show you some of them on the screen. They are very common in all stagnant water. I have chosen for my illustrations one which is named amœba, or the proteus animalcule—so called, because it is always changing its form, and you never see it alike two moments together; and the actinophrys, or sun animalcule, because it has rays like the sun. First, with regard to this amœba, it is very common in stagnant water where there is a good deal of decaying vegetation. If you look at it under the microscope, you will see that it soon begins to push out some part of its jelly-like body like a great broad finger, then the rest of the body seems to flow into that projecting part, and so by and by the whole body moves to that place. Sometimes the projection comes out in another part; sometimes five or six projections stand out at once; so it is always changing its form. As you see it on the screen, you have a fair idea of what it is like; on the outside of it there is a thin dark line representing the surface, and then rather a firmer layer of jelly before getting to the inside. The surface layer of the jelly is a little thicker than the rest. The way in which this creature takes its food is to walk into it wherever it meets with it, for it no sooner comes into contact with any particles of decaying vegetable or animal matter

than the jelly spreads over those particles, and encloses them in the body, where they are digested as if the creature had a proper mouth and stomach. The actinophrys does just the same, only instead of moving about it generally remains still, spreads out its long rays like a spider's web, and catches anything which touches the threads. The actinophrys, also, is found in stagnant waters. It is able to catch very active living things. If one of these active creatures, such as a small water flea, touches one of the rays of the actinophrys, it is stopped in a moment; you then see it slide down until it touches the body, it sinks into the jelly until it is covered over and is buried inside. In both these cases you see that the food is taken in without a mouth and digested without a stomach. This is digestion in its simplest form. You can see the whole process of the solution and absorption of the food, and its diffusion through the body. These creatures can be found in almost any ditch in our own neighbourhood.

I now have to speak of creatures like these, but found in the sea. They are called foraminifera, and I have represented one upon the screen. You will see that long threads project from the body of these foraminifera, as they did from the actinophrys or sun animalcule; but there is a peculiarity here, and it is that the body is covered with a beautiful shell. The animal is composed of nothing but soft jelly; there are no organs or parts in it. It puts out long threads of its own substance (soft jelly) in all directions, and they are so soft that wherever two of the threads touch they blend, and so you have a sort of irregular net work formed round the animal. This net work is spread out to catch its food, and whatever touches the net is drawn into the body and dissolved for nourishment. The shells of these creatures are of all manner of beautiful shapes, and it is wonderful that this soft jelly can produce such regular forms. The shell is made of carbonate of lime, which is derived from the sea water and it is deposited by the animal. To do this the jelly must form itself into a regular shape; it may be the shape of a bottle or some other shape, such as those you see on the screen, and it must remain stationary, acting as a mould while the carbonate of lime crystalizes, as it were, over the surface. In that way the creature gets a covering of shell from lime derived from the sea water. You will notice in some of those cases that the shell does not consist of one chamber only, but of many. These foraminifera grow with the nourishment they take in, and to accommodate themselves they now and then add a fresh apartment to their house. They begin with a little chamber, and add the others, one

by one, as they grow bigger. You will see that this mode of formation of the shell is necessary, because it is formed upon the surface of the animal, which makes itself a mould for the shell; so that as soon as ever the shell is made the animal is big enough to fill it, and it no sooner grows than its house becomes too small, the additional soft jelly is then spread on the outside of the shell until there is enough of it to fill a new chamber. Thus the foraminifera grow by feeding and adding new rooms to their house as required, and in that way beautiful many-chambered shells are formed, some of them like the nautilus shell. The pictures I show of these shells will give you some idea of the variety and beauty of their shapes. The name foraminifera has been given to them because of the many little holes or foramina with which the shells are perforated.

These foraminifera exist in prodigious numbers in the sea. They are quite microscopical things. In many places the sand of the sea-shore is scarcely anything else but these shells, and you would trample it under foot without suspecting the thousand forms of beauty it contained. All those little atoms were once inhabited by living things, which have produced those beautiful forms. There is one place on the West Coast of Ireland, from which I have received quantities of these shells, and the whole of the sea-shore is composed of nothing but these remains of foraminifera. At that spot you may walk for miles upon them, and at every step would trample upon thousands. Not only the sea-shore, but the whole bed of the ocean is in many parts formed of them. The bed of the Atlantic for instance, all the way where deep-sea soundings took place in preparation for laying the telegraphs, is filled with these minute shells, which exist at the bottom of the sea in the form of a white paste, like soft chalk, many of the shells being broken up by the action of the water. It is a fact that the chalk rocks, which in some places are very extensive, are composed almost entirely of these foraminifera. Not only chalk rocks, but many other geological formations, including different kinds of clay, often contain immense numbers of these shells of foraminifera; and there is every probability that many kinds of limestone are formed chiefly of their remains. Limestone of different kinds is of the greatest value to us, in a commercial point of view; we use it for building-stone, for mortar, and for many other purposes, and it is well to remember that all this stone is in great part the product of these apparently insignificant creatures. The next picture represents a piece of beautiful marble statuary, and I have

exhibited it as an example of one of the highest purposes which limestone is made to serve. Marble is limestone in a crystalline form. Some of our marbles, like that of Derbyshire, are formed from the remains of larger kinds of fossil animals, giving to it when polished, its peculiar markings. Other marbles consist of crystallized limestone, altered since its first formation, so that the animals to which it owes its origin can no longer be recognised, and of this kind the pure white marble used for statuary is an example.

You see in an example like this to what important uses little things are turned in nature. Do not think that the work is done when life is ended. These creatures lived perhaps millions of years ago, and died, and there it might appear was an end of them. They sank to the bottom of the sea, and if any man had seen them he might naturally suppose that all was over with them, but they were then beginning to form this limestone in the bed of the sea. Changes have taken place since, and that stone, having become hardened, is now one of our most useful substances. We may learn then from this that there is nothing insignificant in nature; there is nothing so small that we should overlook it. The large things that we notice first are few in number comparatively; and their influence is comparatively small, it is the little things that we can scarcely see that by their prodigious numbers really produce the greatest effects. This is the case with the little creatures of which I have been speaking, the numbers of which are so immense that they have produced perhaps greater effects upon our globe than any other living beings.

I must now say a few words about sponge, with the appearance of which you are well acquainted in its commercial form. There are many kinds of sponge, but only a few that are useful to us. What you know as sponge is the skeleton; it consists of a horny substance forming a fine network which is very elastic, so that if you squeeze it, it springs open, as soon as you let it go, and if put into water, it sucks the water up until the sponge is filled; hence its use. The sponge when in a living state, was a collection of little animals like the amœba, and these little animals, growing in a large company, have the power of forming within them a framework, upon which they are supported, so that they can live together as a colony. There are some sets of these small animals in the sponge with little tails, and these tails or filaments are always moving in a particular manner, which draws water through small holes on the surface of the sponge, and this water after passing through all

parts comes out again in streams from a few larger openings provided for the purpose. In drawing in the water in this way, the sponge animals draw in at the same time the little living creatures in the water, and so get their nourishment. Many sponges are not useful for household purposes, because, besides the horny substance, their network contains a great number of spicules made of carbonate of lime or of flint, but these form beautiful objects for examination under the microscope.

I shall next pass on to the infusoria, or water animalcules, which exist in enormous numbers in every stagnant pool. They are called infusoria for this reason—if you make an infusion of tea, hay, and any other vegetable matter, that is, pour boiling water upon it, after letting it stand for a few days, you will find the infusion full of living things. If you take a drop of it, you will find it to contain thousands of these little creatures swimming about. There are a a great many different kinds of them, some larger and some smaller; those you get by infusion at first are very small, and called monads. I shall show you a diagram of one of the larger kinds. You will perceive that this animal is very much like the amœba in its general character. It has rather a firm outside coating, and the inside is of soft jelly, but the body has a thin skin, and is covered on the surface by hairs. In one part of the body there is a sort of funnel-like opening, and that is the mouth. These infusoria have a mouth, and in that they differ from the creatures I spoke of before; they are considered, in consequence of this mouth, to be a good deal higher in the scale of animal life. The mouth is surrounded by hairs as well as the body covered by them, and the hairs continually vibrate. By the motion of the hairs on the body, these creatures can swim rapidly through the water, and by the motion of the hairs about the mouth they draw water into the funnel, and along with it the little creatures that serve them as food. They go in through that funnel to the bottom, drop into the soft jelly, and there become digested as in the amœba. That is the general character of all the infusoria. There are many beautiful forms of them which can be seen with a microscope. I will show diagrams of two forms in order that you may have some idea of what they are like. Many of them are shaped like beautiful little bells, and some of them grow together on stalks like lily of the valley flowers; these stalks are attached to water plants. The drawings I show are of course greatly magnified. The bell animalcules are most beautiful objects to watch under the microscope; they take their food in the manner before

described; sometimes a larger piece than usual goes into the mouth of one of them and seems to choke it; suddenly it shuts up, and it is pretty to see how all the other little bells on the same stalk sympathise with it, and shrink up their flowers, the stalks at the same time contracting and twisting into a corkscrew shape, so that what was before a large spray of beautiful flowers becomes a close bunch of shut up buds. After a time they gradually unfold themselves, the bells open out, the hairs vibrate, and the streams of water enter as before. The lower picture represents the trumpet animalcule, so called because it looks like a trumpet. The character is the same as that of the others, but there is no slender stalk, the body itself being fixed to some solid substance. It is very interesting to watch these creatures, and you can see a great portion of their mode of life by watching them for half an hour now and then. Sometimes you may see that one of the bells is beginning to split down the middle and form into two. After a time, one of the two will break off and swim through the water as a free and separate creature, and in that way they multiply to a great extent.

Now, what is the use of all these infusoria which fill our stagnant pools? I think their use is clear enough. They are found where there is vegetable matter in a state of decay, and which would soon make all the water putrid and bad, so that it would become very unhealthy and disagreeable, if not actually poisonous. See here, again, how these little things—which are so small that we have to use a powerful microscope to see them—keep the whole earth sweet by their countless numbers, and their constant consumption of decaying organic matters.

Now in this lecture I have shown you creatures which illustrate my text of Life without organs. I have shown you that these microscopic jelly-like beings are alive. We can see that they have life in them, but we cannot tell how or why it is so. This shows you a very important fact to remember—that life does not depend upon organs such as we have; it does not depend upon stomach, bones, muscle, and brain, excepting where the life is of a high order, where it becomes necessary there should be a division of labour, one part of the body performing one duty, and another part another duty; but it is not necessary for the presence of life that the body should be divided into organs.

I may say one word about organisation and what is meant by it. An organisation is a body formed of organs, and an organ is a structure having a distinct or proper duty or function to perform, which it does for the good of all the remaining organs in the body.

It is a case of division of labour. All animals are generally said to be organized; I have shown you that these lowest are not organized, in the sense of possessing organs ; and there are many things organized besides animals. A steam engine is an organization, for each part of it has a distinct function to perform, and does it in connection with all the rest, just as is the case with the different organs of a man's body. Do not confound organization with life. Life can exist without organization, and organization can exist without life; but wherever you have life of a high order, there you have organization, because you require a division of labour in the body in order that it shall rightly perform its functions.

In conclusion, I will show you a drop of water from a pond with some live things in it; but first I would explain that the water you drink has nothing of this kind in it at all; they are only found where there is decaying animal or vegetable matter, and they are there because their business is to eat it. You see they are very active about their work of eating up the dirt, and you have a proof how well they perform their duty in the fact that if you have an aquarium, and keep the water in it for months in the house, it does not smell, because these active creatures are continually eating up the decaying matters, and keeping it fresh and sweet. I believe I am telling nothing but the simple truth, when I say that the possibility of the existence of higher forms of life upon the earth depends very much upon these microscopic beings which keep the waters pure.

ZOOLOGY,

OR

FOUR PLANS OF ANIMAL CREATION.

LECTURE II.

SECOND PLAN.—STAR-SHAPED ANIMALS—STOMACH.

RADIATE plan of structure. Body consists of repetitions of similar parts arranged round the mouth and stomach. Fresh-water Hydra, common in ponds Description. It uses its arms or rays like a fishing-rod and line to take food. Means by which it secures its prey. Produces young ones by buds growing out from the body.—Marine Zoophytes, common on all shores. Plant-like compound animal. Resembles a large colony of Hydras, remaining attached to one another and having the surface of their bodies hard and horny.—Jelly-fishes; must be seen swimming in the water to be understood. Description. Small quantity of animal matter contained in them. Stinging organs; their structure and use.—Sea Anemones common on all rocky or stony shores. Description; structure, stomach contained within the cavity of the body.—Sea Anemones at Fleetwood, Blackpool, Llandudno, and Beaumaris. Madrepore; compound Anemones, with their bodies strengthened by deposits of carbonate of lime. Coral Reefs. Gorgonia, Red Coral.—Starfish; description, body extending in rays around the mouth. Nature of locomotive organs. Habits and food. The Starfish a walking stomach. Many kinds of them, Sand Stars, Brittle Stars. Dredging in the Menai Straits. Brittle-stars breaking off their arms. Vegetative repetition of parts a sign of low organisation. Lost parts of Star-fish grow again.—Sea Urchin. Description, Habits and food. Its locomotive organs; spines and suckers. Pedicellariæ, singular organs to drive away parasites. Mouth and teeth of Sea Urchin. Digestive organs.—Conclusion.

You remember that towards the end of my last lecture, I told you about the infusoria, and I showed you that they have a mouth, though all the interior of their body is soft jelly. In animals made on the radiate plan, such as I have to speak of to-night, there is a stomach as well as a mouth, and this stomach is clearly a matter of great importance in them. It is a chamber or hollow in which the food is received to be digested, and the liquid nutriment which results from digestion passes through these walls, and is then distributed through all parts of the body. The common starfish will give you a good idea of the plan of structure of a radiate animal. The mouth and the stomach are in the centre, and round these are arranged all the other parts of the body, and they stand out like rays in all directions. You may form a pretty correct notion of the manner of life of these animals if you have seen a lot of boys about a bonfire. You have seen that the boys stand round the fire in a ring, and go as near to it as they dare, in order to get equal shares of the fire and the fun; then, if you watch them for a time, you will see that first one and then another of them will be collecting fresh fuel, and throwing it on, so as to keep up the blaze. This is just the use of the projecting parts of a starfish, or other radiate animal; they are servants of the stomach, and they are continually seeking articles of food, to be put into the mouth. Now, the first radiate animal that I shall show you to-night is one which is common in the ponds in this neighbourhood, and it is called the fresh-water hydra. I shall show you one on the screen. Mr. Brothers has been kind enough to obtain the specimen for me, and put it in a suitable slide for showing upon the screen with the lantern. There are several kinds of fresh-water hydra, which are distinguished by their colour; some of them being green, and others of a brownish colour, and by the length of their arms, one kind being remarkable for having very long arms. This which I show is one with arms of an intermediate length. Though they are common enough, not many of you probably have had an opportunity of seeing them. It now begins to lengthen itself. You will see that the creature is formed with a rather slender body, and that from one end of this body proceed a number of rays or arms. These arms have the power of lengthening themselves, so that they become quite slender threads. In this case you have a young one growing from the body of the larger hydra; it may be seen standing out like a bud from the side of a plant. These hydras all through the summer produce young ones in this way. At first they are very small, and have no particular form in them; but as they grow larger

their little arms or rays spring out from the end, and after a time they take the perfect form of the hydra, but are still attached to the parent; as soon, however, as they become perfect animals, they separate from the parent, and begin life on their own account. You see in this specimen the arms are very broadly spread out in a ray-like form from one end of the animal. The centre of these rays is the mouth, and in the inside of the body is excavated a cavity, which is the stomach.

The hydra is a fishing animal, and its rays serve it for rod and line. Whatever little swimming creature touches one of these rays is instantly caught; then you will find that the ray shrinks up, carrying its prey along with it, until the object caught is conveyed close up to the mouth, and it is then pushed into the cavity of the stomach. There is one kind of hydra occasionally met with in this neighbourhood, but not so commonly as the one I have shown, which has very long arms; the body is about three-quarters of an inch long, and the arms are four inches or more in length. It is called hydra fusca. This creature uses its rays so exactly like a rod and line, that I have often thought an ardent angler might find excellent sport by watching these hydras at home, when the weather or other circumstances prevented him from using the rod and line for himself. They do their fishing, really, in a most scientific manner. If you watch these animals feeding, you will very naturally wonder how it happens that active little swimming creatures should be so instantly caught by those delicate threads of the hydra. Whatever part of the thread is touched by one of these creatures it instantly sticks there. Now, you must remember that these rays are not made of soft jelly, as was the case with the animals I spoke of last week. They are pretty firm in their substance, and if you magnify them very greatly, you find how it is that they catch their prey. You find then that there is a very curious mechanism for the purpose. These slender rays which serve for fishing lines, are covered all the way down with little cells or bags, each having inside of it a long, stiff, spiral thread, and these spiral threads in the cells are kept set like so many traps, and they are no sooner touched than they go off; out shoots the spiral thread, and wraps round and entangles the prey, draws it closely up against the arm of the hydra, and at the same time presses it upon some little spikes that stand out from each of the cells, and in this way, the object caught is securely fixed. These hydras are really very interesting little creatures, and they have served for a great number of curious experiments. You may

take a hydra, for instance, like one of those you see on the screen, and cut it up into little bits, and it is found that every one of these bits will not only live, but after a time will grow into a perfect and complete hydra, having rays at one end, and a sucker at the other. The sucker is intended for the animal to fix itself upon any object, for the purpose of fishing conveniently. If, then, you happen to have only one hydra, and wish to have many, you have only to cut him up, and you may make as many as you please. You have seen in the specimen shown on the screen, that the hydra produces young by buds growing out from its body. These continue to grow until they get to a tolerable size, and when fully able to work for their living, they break off from the parent, and set up in the business of fishing on their own account. In this way, by the production of buds, the hydras continue to multiply all through the summer, but towards winter they produce young ones by eggs, which remain until spring, when they are hatched, and so continue the race.

The sea contains immense numbers of creatures nearly related to the fresh-water hydra; those which are most noticed by people who go to the sea-side, are the horny zoophytes. These horny zoophytes—one of which I can show you on the screen—are objects which you may see tumbled about by the tide on any shore, and they are very much like plants. They are of a pale yellow colour, of a horny texture, and are very much divided into slender stems and branches. What you thus find on the shore are the skeletons and remains of the outside part of large colonies of hydra-like creatures, which form buds in the same way as the fresh-water hydra, but these buds, instead of breaking away when fully formed, remain attached to the parent, and so a large colony of compound animals is formed. The object nearest to me on the screen is a little twig from the top of one of these horny zoophytes. At the extreme points of the twig you will see a little flower-like object, similar to the rays of the fresh-water hydra. These are the rays which surround one of the mouths of this zoophyte, and beyond the mouth is a small stomach. They grow in great numbers together, and are connected by the stems, all along which you have hollow tubes which are filled with the nutrient material from all the stomachs of these animals that are thus growing together; and they form a sort of co-operative store, to which all contribute their share, and from which all can take what they require. These plant-like, compound animals are very common upon all our shores. You may find plenty of them at Southport, and on the sands at Lytham. At Beaumaris you may see

these objects living and attached to the rocks and stones, where they naturally grow; and you could not have, I think, a more beautiful sight than you may obtain at Beaumaris, by wading into the water, when the tide is fully out, up to your knees, and then walking along in a line parallel with the shore. For miles you may go through groves of these living plant-like animals and sea-weeds; among them, you will see all manner of curious and beautiful sea creatures, but it is the zoophytes which are there so remarkably beautiful. I should advise you, then, if you ever find yourselves at Beaumaris, just to take this hint, and wade into the sea at extreme low water, on a calm day, and you will be well rewarded for your pains.

We will now leave these zoophytes, and go on to another class of objects, which have also a radiate or star-like character. If you walk upon the sands at Southport, you will be pretty sure to see plenty of rather unpleasant-looking objects, like shapeless lumps of jelly. These, you know, are commonly called "jelly-fishes." Now, these unsightly creatures are amongst the most beautiful objects in nature

If you take the trouble to put one of them into the water you will prove this for yourselves. Remember, that these creatures live in water, and if you would see them in their natural state, you must see them in it. I have often thought if the fishes were to take it into their heads to study natural history, and, in order to examine the human species were to put us under water to inspect us at leisure, we should cut a very sorry figure; to examine the jelly fish out of water is just as wise on our part. If you look at this creature in its natural condition, as you see it represented now on the screen, you behold a creature transparent as glass, with a top shaped like an umbrella or mushroom, hanging from which are elegant tassels and tendrils. This is the way the creature looks when alive, and if you watch its movements in the water, you will observe that its way of swimming is by a series of pulsations of that umbrella-like top. The movements of the creature are most graceful, and the object itself is really very beautiful. The way to see these creatures in perfection when you are at the sea-side, is to choose a perfectly calm day, and go out in a boat, and in an idle humour paddle along; you will then, in all probability, see many of them swimming near the surface of the water. In the Menai Straits I have seen the water covered with them, and amongst them I once noticed one as much as a yard across, which is very large for a jelly-fish. These jelly-fishes, as you know, are said to sting very severely, and one so

large as that I have just mentioned would, no doubt, be a very serious thing for a swimmer to meet with. The jelly-fishes sting by means of a peculiar mechanism, something like that of the hydra, but more complicated. There are what are called "poison cells" scattered over those tendrils that hang down from the lower part of the jelly-fish, the structure of which is this,—inside each cell there is a spiral thread and also a poison dart, and when these cells are irritated by anything touching them, the dart and spiral thread are thrown out and pierce the object that comes against them.

The jelly-fishes are remarkable for the enormous quantity of water they contain, and the very small quantity of animal matter. This proportion of water is so great that if you take a jelly-fish, weighing two pounds, and drain out the water until it is dry, you will not have more than thirty grains of solid animal matter left. I dare say you may have heard the story of the farmer who lived not far from the sea-shore, and who one day went down to the sea-side to look about him, and, as sometimes happens, the sea had thrown up a prodigious number of these jelly-fishes, which were lying about on the shore. A brilliant idea struck him—that here was a chance for him to fertilize his land without the expense of buying manure! So he hurried home, sent down his waggons, and had them loaded with these jelly-fish, which he conveyed home with great labour and laid them down in his farm-yard. At the earliest dawn next morning, he looked out to see how his manure was getting on, when, to his dismay, he saw nothing at all, and imagined at first that some unprincipled neighbour had carried away his valuable material in the night; but on looking more closely, he discovered that, the sea water having drained away, there was nothing left but some almost imperceptible films of animal matter! So large is the quantity of water contained in these creatures, and so very small the quantity of animal substance.

I must now go on to speak of some other radiate or star-like animals, and those I shall choose next will be the sea anemones. I will throw a sea anemone upon the screen, and along with it a number of other radiate animals, so that you will have a group of these creatures, and they are, as you see, very beautiful objects. There is great variety in the form of sea anemones. The one you now see has a body like a tall, straight pillar; the mouth is, as usual, in the centre of the top, and there are long threads hanging down from around it; those are rays, like the rays which surround the mouth of the fresh water hydra. That is the general character

of all the sea anemones; but in most cases the rays or arms are much shorter than in the example before you. Most of the sea anemones are very much like flowers. At the base is a sucker-like disc, by which they attach themselves to rocks and stones. You may get a good idea of the structure of the sea anemone by comparing it with a poppy-head. I dare say you know that if you cut a poppy-head across, you will have the appearance of an outside ring with a number of partitions verging towards the centre. It is just the same if you cut a sea anemone across, only that in the latter you cut also across the stomach, which joins the partitions as they come towards the centre, and forms an inner ring. You can find sea anemones on almost every shore you may go to. I never saw them more beautiful than at Fleetwood. If you go down the river at low water in a boat, and land on any of the flats that are then exposed, you will enjoy a sight that will well repay you. You will see a sort of bed of shingle or stones covered with great masses of the cases of worms, which live in company, forming the most extraordinary towns and cities of worms. There are thousands and thousands in one mass, and they occupy a good portion of the surface of these flats of shingle, and between them are pools of water, full of magnificent sea anemones, like gardens of the most beautiful flowers. When I was looking at them, and thinking they were almost too delicate and pretty to eat at all, I was shocked to notice a particularly charming one trying to cram into its mouth a mass of food a great deal larger than itself—so greedy are these radiate animals, and the sea anemones are no exception to that rule.

At Blackpool you cannot find many sea anemones, and perhaps you will find none, unless you know what to look for; but upon the sandy parts of the shore you may pick up some beautiful ones that have been detached from rocky ground deep down in the sea and thrown upon the loose sand. When found, they look like shapeless pieces of flesh, but soon open out in sea water. On one occasion, I found a very beautiful one there, fixed firmly on the back of a large crab. I carried home my capture in triumph, placed it in a large glass of sea water, and, during my stay at Blackpool, it formed a conspicuous object in the window of my lodgings, to the admiration of both natives and visitors. At Llandudno there are plenty of them, and at Beaumaris the shore is all studded over with them. At Llandudno you may have a great choice of very beautiful ones, and you may see how the same species will vary in colour. I have had as many as twenty of the same sort, each as big as a large dahlia flower, and not two of them alike in colour.

There is a wonderful place for sea anemones and all kinds of sea creatures at the entrance of the Menai Straits; it is called the Beacon Rock, and stands midway between Puffin Island and the nearest point of Anglesea. If you go there at low water, you will find the most curious creatures, and when the tide is out you can get into a remarkable cave which is completely covered at the top, sides, and floor, with sea anemones, forming as extraordinary a sight as you can well imagine.

I must leave these creatures now, and speak of the madrepores, which are not found on our own shores, but belong to tropical seas. The madrepores are similar to sea anemones, but they have this peculiarity, that the substance of their bodies is made firm by deposits of carbonate of lime, and they also grow together in company. You see there a photograph of the skeleton or hard part of a mass of these compound sea anemones or madrepores. From every one of the tips of those branches in a living state would appear a beautiful flower like a sea anemone. You see that in this case the object has quite a tree-like appearance, and this will prepare you to understand how it was that not so very long since naturalists were undecided whether these creatures were really animals or plants. It might have been some such specimen as that on the screen which convinced a certain French naturalist on this point. He had been for his holiday to the shores of the Red Sea, and when he returned home he made haste to communicate to some learned society his great discovery. He was happy, he said, to be able at once to end the controversy as to whether these things were plants or animals, for now he had positive proof that they were plants, for he had timed his visit to them so fortunately that he had seen them in their native element *in full flower!*—those flowers, of course, being nothing more than the mouths of the compound animals: so difficult is it for us to get at the truth, because men will guess instead of going to the trouble of careful and thorough examination.

The coral reefs, which you must have heard of, and which are so massive, and form such extensive rocks, as it were, in the oceans of tropical climes, and especially in the South Pacific, are formed entirely by animals belonging to this class. The animals keep depositing lime in the substance of their bodies, and when they die a hard skeleton remains. Fresh colonies of them grow on the top of those that have gone before them; fresh carbonate of lime is taken in from the sea water, digested and deposited in their substance, and thus, in the course of time, enormous masses of this madrepore are formed in the sea, so much so that they

make reefs which are often very dangerous to navigation. Many of the islands in the Pacifie are formed entirely of these coral animals; others are surrounded by rings of coral reef, and these frequently afford a safe and welcome anchorage for ships. It seems strange that creatures individually so insignificant should produce such enormous results.

There are other creatures I shall have to direct your attention to, and I will at once show you one upon the screen. These creatures differ from the madrepores; they have a firm, hard skeleton, but it is of a horny substance. The one nearest to me is well known by the name of Venus's Fan. It is a complete network of horny substance. This is the skeleton of a thing which, when alive, was coated over with a fleshy animal matter, the whole of which was set with little flowers, as it were, each consisting of a circle of tentacles or feelers, in the centre of which was a mouth leading into a stomach; and the whole of that object has been secreted in the inside of a great colony of such like creatures, which make that skeleton for their support. These are called gorgonia, and they lead me to speak of another object which is, perhaps, of more interest—this is the red coral. Now red coral is quite a different thing from the large masses of madrepore, which often go by the name of coral. Red coral is a horny skeleton like that, but made perfectly hard by deposits of carbonate and phosphate of lime. It is formed by a fleshy substance like the gorgonia, that fleshy substance having imbedded in it a great number of little mouths which draw in nourishment, and are really the individual animals which produce the whole thing. On this slide you see represented a small piece of the red coral, with a part of the skeleton laid bare, showing what is known as coral; the other parts are covered by a fleshy substance, and scattered here and there upon that you see the mouths with the flower-like tentacles by which food is taken in.

I must now leave all these compound animals, and say a few words about the highest group of radiate animals, the star-fishes and creatures of that kind, which are always single, individual objects, and have generally the power of moving from place to place. The common star-fish is very abundant at Blackpool; you may see it by thousands on the shore; and perhaps one reason for its abundance there is that it finds its natural food on the shore. It feeds upon bivalve shellfish which live buried in the sand, and you may find it at any time there busily engaged in eating cockles. You see a specimen of this starfish on the screen. Now this star-fish is literally a walking stomach. The centre of

the animal is a stomach, and the rays project from it in the way I pointed out at the beginning of the lecture. One thing that is very remarkable about these star-fishes, is their extreme carelessness about their limbs. If you pull one off they don't seem to mind it. At Llandudno I saw one so careless that when fixed to the side of a perpendicular rock by one ray it allowed the weight of the body to break it away, leaving the one ray behind sticking on the stone, so little do they mind the loss of a limb. At Blackpool I have seen one that had all its rays pulled off, and nothing but the round body in the middle left, and yet it was going about quite heartily. These star-fishes are so careless about their appendages because they have the power of reproducing them; they grow again, and you may often see star-fishes in all stages of reproduction of lost limbs.

There are a great many kinds of star-fish. One of those shown on the screen is called the sand star. In that case the rays are long and slender, so that they are thought to be like the tails of snakes. Now, this sand star is extremely reckless about its appendages; it does not wait for you to pull them off; if you only touch one of them, it snaps it off of its own accord; and it is very difficult to catch one whole. The way pursued by naturalists is to take a broad paper-knife, put it under the creature,—taking up some sand as well,—then plunge it into a bucket of fresh water. In that way the creature dies instantly, before it knows what you are doing, and has not time to snap its rays off. There are other kinds of star-fish even more irritable than the sand stars, and they are called brittle stars on that account. When I have been dredging in the Menai Straits, I have brought up the dredge quite full of these brittle stars all matted together, and the sight of them was one of the most annoying to a naturalist that can be imagined. There they were of every conceivable colour and pattern of marking, and all snapping and breaking to bits before my eyes, and nobody touching them! You find in all these star-fishes many repetitions of the same parts: that is a number of parts performing the same functions; and whenever this is the case you may be sure it is the sign of a low organization; and together with this repetition of similar parts you find that there is a corresponding power of reproduction in them when they are destroyed by any accident. If you collect a number of these brittle stars you often find some of them with young rays growing out to replace those which they have lost at a former time.

I must now say a word or two about another kind of radiate animal, agreeing in some respects with the star-fish but it is

globular in shape, instead of being divided into rays. It is called the echinus or sea urchin. It consists of a hard round shell, and that shell is covered with spines, which stand out in all directions. The star-fish is an animal feeder, but the sea urchin is a vegetable feeder.

The common echinus is very abundant at Beaumaris. At low water there you may find them in great numbers upon the shore sticking to seaweeds, or fixed amongst the stones. It is curious to watch the echinus; it walks upon stilts, as it were, by means of the long spines that project from it; and, in addition to these stilts, it has a kind of suckers, which are put out from five rows of little holes round the body, and these lay hold of any fixed substance upon which the creature is walking, and so steady it in its curious mode of progression. The echinus is a creature very well worth examination, and a good deal of its structure can be seen without a microscope. Among the spines of the echinus, all over the shell, will be found a number of very singular things, which I have put down in the syllabus by the name of pedicellariæ. These are long worm-like objects, at the end of each of which you find three hard calcareous jaws which fit together, and look like the head of a snake. When the echinus is alive these jaws continually open and shut, and their object is to seize upon or drive away any parasites that might fix themselves upon the echinus and impede the movements of the spines. The digestive organs of the sea urchin are remarkable. In consequence of their vegetable food these organs are much more complicated than they are in the star-fish; the mouth is provided with a singular arrangement of teeth and jaws, and there is an intestine as well as a stomach, for the sea-weed upon which it feeds requires a good deal of digestion and preparation to convert it into animal material. You will perceive that in all these radiate animals the stomach is *the* important part of the creature, and by its appearance here in these low kinds of animals, and by the prominence given to it, we may be taught that it is the organ which is most essential to animal life; for it is by its means that the various articles of food taken in are dissolved and converted into compounds suitable to be built up into the body of the animal, and to be made a part of its substance.

In my next lecture I shall give you an account of jointed animals, and I shall show you that the prominent idea in them is the development and perfection of the locomotive organs.

ZOOLOGY,

OR

FOUR PLANS OF ANIMAL CREATION.

LECTURE III.

THIRD PLAN.—JOINTED ANIMALS—LOCOMOTIVE ORGANS.

JOINTED plan of structure. Body consists of repetitions of similar parts placed end to end. The Leech, the Earthworm. These are among the lowest of jointed animals. Description of each. The chief idea in all jointed animals is locomotion; how the Leech manages it. Locomotion in the Earthworm; habits of the worm. Various kinds of Marine Worms all showing the jointed structure in its simplest form. In further developments of this locomotive plan we have two distinct sets of jointed animals; one set living in water, such as Shrimps, Lobsters, and Crabs; the other set living in air, as Centipedes, Insects, and Spiders. The Centipede: description,—body with many joints, a pair of legs on each except the first and last—good intentions, great show and little work—Locomotion implies muscular action; chemical change like that which takes place when a candle burns; the breathing organs bring the Oxygen required and carry off Carbonic Acid. Close connection of breathing organs with those of locomotion in jointed animals. Nature of Gills. Crab, Crayfish, Common Crab, description. Habits, quarrelsome disposition. Voluntary amputations and growth of new limbs. Casting the shell. Cannibalism. Locomotion in Insects. Two requisites for flight are extreme lightness of the body and the greatest possible energy and endurance of the muscles. Arrangements by which these results are

obtained—Caterpillar, Chrysalis, and Butterfly. Nature of wings. The Dragonfly, description; different stages of its existence. Perfection of flight.—Conclusion.

In my last lecture I showed you some living Hydras, and I told you of one kind called Hydra fusca. I told you it is remarkable for the length of its arms, and their exact resemblance to a fishing rod and line. I shall now show you on the screen some portraits, taken a few years ago, of specimens of these hydras, so that you may see what their character really is. You will see here one of these objects floating, as they often do, upon the surface of the water. In that case the disc or sucker at the end opposite to the mouth is used as a float, the body hangs down in the water, while the rays stand out stiffly for a part of their length, and then, becoming very slender, hang down like fishing lines. In one instance you see the line twisted; it has just caught something and carried it to the mouth: it is now being thrown out to try its luck again. You see the hydras represented in many different positions. Here is one with a bud attached to its body, like the one you saw living last week. Here is one which has taken in a large meal, and is shut up for a time while it digests its food. Here is another walking along the bottom of the vessel upon its contracted rays, and looking like a star-fish. And here again is one which is going along in the manner of a leech, by bending the body into a loop, and holding alternately by the sucker and the contracted rays.

To-night I have to speak of jointed animals, in all of which the chief idea is locomotion, or moving from place to place. We find among them all sorts of designs for effecting this object, some more and others less efficient, but in each case exactly suited to the requirements of the animal possessing them. The outside of the body of all jointed animals is firm and strong; and it is often quite hard; in which case it consists of many pieces jointed together, so that they can be moved on each other. The simplest plans of locomotive structure are seen in the different kinds of worms, and of these the leech is the most remarkable. It has not the slightest trace of any external locomotive organs, and yet it can get along in the water much better than many creatures that have limbs. We are so familiar with the fact, or else we should think it very odd to see a creature five or six times as long at one time as it is at another; no one thinks it wonderful in the leech, because we all know it is its

nature to do so. At each end of the body of this animal there is a sucker by which it can fix itself either at the one end or the other, as it requires; and it performs its movements by the harmonious action of innumerable muscles which form the walls of its body. The action of these muscles is regulated by a system of nerves which look like slender white threads, coming from small knots of nervous substance, as you see in the picture which is now on the screen; those knots of nervous substance extend down the middle of the body, and are connected together by short nerves so as to look like a string of beads. This nervous system may be very well compared to a set of telegraphic wires, through which messages are continually being sent to different parts of the system, and the string of beads which you see down the middle of the body might be compared with so many local stations, each acting within its own district; but the principle office is in the head, where there is a larger mass of nervous matter which may be called the brain. It is from this mass of nervous matter in the head of the animal that general directions are sent through the whole system of nerves to regulate the movements of the whole, and you have here in the leech a most complicated system of muscles and nerves to produce those movements required for its peculiar kind of locomotion. If you were to allow a man his whole lifetime to make a working model of the leech, he could not do it, simple as this animal looks.

Leaving the leech, I shall now say a word or two about the common earthworm. This is a very interesting little creature. It is formed in every respect for living under ground. The rings of its body are more plainly marked than they are in the leech. Its body may be said on the whole to be cylindrical, but at the front end it is conical, and comes to a rather fine point. At the hinder part, the body is flattened above and below, so that it has an edge on each side. This form of the body has a good deal to do with its success in making its way underground. The earthworm has the same power of lengthening and shortening itself as the leech has, but to suit its peculiar circumstances it is also provided on each ring with four pairs of little bristles, each of them having the points directed backwards. You can easily prove this, if you take up an earthworm and pull it through your hands. If you take hold of the head-part of the worm and pass your hand towards the tail it goes without any obstruction but if you try to pass it the other way, you cannot—your hand is held by these little spines. Now, the effect of these spines is, that the hinder part of the worm can be fixed immovably

in its hole, while the front part is being pushed strongly forward to extend the hole in the ground. At the slender front end of the worm is the mouth, which is simply an opening, but just above it there is a little finger, as it were, the office of which is to keep putting soil into the mouth; for it is a fact that the worm to a very considerable extent eats its way through the earth when it is burrowing. The food of the worm is the actual soil; that which nourishes it of course being the organic matters which happen to be mixed with it. During last summer I was making some observations on worms, and I had occasion to dig up as many as I could find in my garden, and I was surprised to see that a very considerable number of the worms I obtained had new tails. It was evident that they were not the original tails, because they were badly fitted; they were smaller in proportion than the rest of the body, as well as paler in colour. I asked myself as well as others how it happened that these worms had new tails, and the only explanation I received was that in all probability the gardener had been digging and had chopped the worms in two. Now, I knew very well that my gardener had not been so actively at work as to chop off all these worms' tails, so I was obliged to seek another explanation, which I think I found. Worms in making their way through the ground and feeding in the manner I have described, eat a great deal of soil, and you know they frequently cast out a large quantity of this soil in the form of worm-like moulds, which you see on the surface. Now if you knock one of those heaps on one side, you will find a worm hole immediately under it. It is clear then that the worm must come up tail first to void this rejected soil. Now that being the case, it struck me at once that birds on the look out for something to eat would very soon spy where a worm was in the act of producing one of those little heaps, would hop to the place, lay hold of the worm and try to pull it out of its hole. But I told you that the worm has the power of resisting strongly being pulled in that direction; it won't come, but will sooner submit to having its tail bitten off; so you see how Providence orders these matters—the bird gets a good meal, and the worm goes back to its hole and grows a new tail!

There are many kinds of marine worms, and among these many that crawl about quite actively; some of them, however, are stationary, and live in cases which they make for themselves. I will show you one or two of these marine worms. You see represented there two kinds of marine worms. The one nearest to me is that which is very much used by fishermen for bait. It

is found living in the sands at Southport abundantly. The other is one of those which make cases of a sort of shelly material, in which they constantly live. In both these you have examples of gills upon worms, gills for breathing or aërating the blood. In the worm nearest to me those gills form little excresences extending a considerable distance along each side of the body; in the other case the gills look like beautiful plumes, and stand round about the head. There are many other marine worms which are not stationary like those two, but crawl about very actively. Their bodies are composed of many rings, and on each ring there are two bundles of bristles, which can be drawn into the body, or pushed out as required; and in walking they move upon these bundles of bristles. Now, in all these examples of worms that I have given you, the body consists of nothing more than a straight row of similar pieces, and there are either no projecting parts for locomotion at the sides of the body, or these are of the simplest character, consisting even in the highest kinds of worms of nothing more than bristles. But all these worms are mere sketches, as it were, of a plan of structure destined to be worked out in other creatures into an endless variety of designs for the most perfect locomotion.

There are two distinct sets of jointed animals belonging to these more advanced plans of structure; one set inhabit the water, and include such creatures as shrimps, lobsters, and crabs; and the other set live on land, and breathe air, and include centipedes, insects, and spiders. I shall now speak of one or two of these creatures, and, first of all, of the centipede. I think I can show you a portrait of the centipede; it is now upon the screen. It shows rather dimly, but sufficiently to discern the creature. The centipede has a body composed of many joints, and this body is firm and hard on the outside. It has a pair of small jointed limbs coming from each ring. Every part of the whole length of the body in this creature is bent upon one thing, and that is locomotion. Every joint has limbs upon it, and each and all are determined to move on. If you watch a centipede walking, you might, at first sight, think that a fair comparison of it would be a long boat with a great number of oars and people rowing; but if you look closer, you will find that that comparison is not strictly correct, for you would see that the limbs are not all moving in the same direction at the same time, but in two or three parts of the centipede you see the limbs are raised to move forward, and between those points there is every gradation of movement; so that, on looking at the whole length of the creature,

the legs appear like a succession of waves passing down the two sides, the waves coming out at the end behind and re-appearing in front. Now, the reason for that is what I told you before with regard to the leech—that there are knots of nervous matter all down the body of the animal; these are connected by nerves which go up to the brain, and the brain keeps sending directions down, and as these go from knot to knot the orders are received by each in succession, causing the limbs to move in that wave-like manner. It is a singular thing that if you take a pair of sharp scissors, and neatly cut a centipede in two when it is actively engaged in motion, the hinder part of the centipede goes on walking just as if nothing had happened! That shows how intent upon motion every part of the creature must be. In this centipede, instead of the locomotion being produced by the lengthening and shortening of the body, as we see it in the leech and in the earth-worm, the joints themselves of the body are fixed, but they have limbs attached to them, and these are moved by muscles contained within the joints to which they belong. Now, this locomotion of the centipede, though it is not very rapid, is very effective to suit the habits of the creature, which are to creep into all sorts of little crevices and winding passages; and it is therefore very important that all parts of its long body should equally be walking forward, because, in twisting and twining itself in a serpentine manner, it would otherwise be continually grating the sides of the passages in which it was moving.

Every movement of the muscles in any creature is accompanied by a wasting of them. A certain quantity of the substance of the muscle is wasted, and at the same time the wasted part is combined with oxygen, which comes originally from the air, and as a result of this change carbonic acid and water are produced. These two substances within the body are thrown into the blood, the blood is then conveyed to the breathing organs, and that carbonic acid and water are there got rid of. In breathing, oxygen is absorbed into the blood from the air, and then we say that the blood, freed from its carbonic acid and water and charged with oxygen, is aërated, and made fit again to be circulated through the body. Now, if you consider, you will perceive that this is a change exactly similar to that which takes place in the burning of a candle, and it is a fact, that just the same amount of heat is produced as is proportionate to the quantity of oxygen used.

I must now say one word about gills, which are the organs used by water creatures for effecting these changes in the blood. Most water creatures are provided with gills, and these gills are generally

composed of a great number of thin plates of membrane, the whole substance of which is made up of a net-work of blood vessels. These blood vessels come on the one hand, from the general system of the body, and contain blood charged with carbonic acid and water, resulting from the combustion of the tissues of the body. That net-work of vessels is freely exposed to the water and it terminates at the other end in vessels which go back directly to the heart of the creature, and then contain pure blood charged with oxygen; and the heart, receiving it in this state, sends it to all parts of the body to continue the same process.

I wish to show you next one of the large class of creatures called crustacea, and I have chosen for my specimen the cray-fish, the common fresh-water cray-fish. These creatures are found very abundantly in some of our rivers and in some canals. I have not met with them nearer home than at Cressbrook; but I have obtained great numbers of them from the canal near Coventry. I have had them sent to me in a common old biscuit tin, and they have borne the journey very well, and lived for months after I received them. I have had every opportunity of examining them during their life with me. I have seen them cast their shells and get new ones; I have seen their eggs hatched and produce young ones, and had full opportunities of seeing the manners and customs of these creatures. That is the portrait of one specimen which I obtained from Coventry. You see it looks very much like a common lobster, and it is really a very similar creature. If you examine that cray-fish or the lobster you will see that it is a jointed animal, but it is very different indeed from the centipede. You have an example in the lobster of the way in which the efficiency of the locomotive organs is increased. You find that the legs, instead of being distributed all down the body, are concentrated at one part, and are placed very near together. The lobster is a water creature, and it is a very good swimmer; but it should be remarked that in this case it does not swim at all with its legs. The hind part of the body, which is commonly called the tail, is really the swimming organ, and you may notice that the end of the tail is provided with a broad fan, and the action of the lobster in swimming is to strike the water downwards by means of this tail, so bringing it suddenly against the under part of its body, the effect of which is to cause the animal to shoot backwards through the water. The lobster always swims backwards, and is said to swim with very extraordinary speed, darting with one flap of its tail many yards, and guiding itself with the greatest nicety, so that it will dart without hesitation into a hole only just

large enough to receive it. You will notice both in the lobster and the cray-fish that the antennæ or feelers are very long. They are made so that when laid flat along the body backwards, as it were, they project in such a manner behind that when the creature is swimming they are of use to feel where it is going, because as I said, it swims backwards. The legs are used for crawling among rocks or stones, where the creature lives.

I shall now leave the cray-fish and go on to speak of the common crab. In this crab we find a concentration of the organs of locomotion the most remarkable in all the crustacea; the limbs are all very close together at their origin, and the whole body seems to be very much pushed up together. If you look at the nervous system in the crab, you will see that it has undergone a corresponding change from what you see in the leech or the centipede. In them there was a long chain like a string of beads. In the crab you will find one large mass of nervous matter in the middle of the body, which sends out nerves like rays in all directions, one large nerve going to each of those limbs to supply it with motive power. You should remember then that in jointed animals the perfection of locomotion is brought about in a great measure by the concentration of the different parts of the body. You are well acquainted, of course, with the common table crab, which you may any day see in the market. The crab is a very interesting creature to examine a little at leisure. Look at the back of the crab, and you will see how beautifully it is arched to resist force, how strong the shell is for the same purpose, how the borders are indented like a pie crust, forming counter arches to increase the strength; then notice how nicely the eyes, which are upon movable stalks, can be put back into the sockets, and how the sockets project, so that a knock on the eye could do it no harm. Then notice the two pairs of feelers, one pair of which fold side by side, and can be put under a sort of roof, where they are quite safe from injury. The second pair of feelers are still more carefully guarded, perhaps because they are more necessary to the creature; they fold in the middle, and can be put away into grooves, looking very much like putting a pair of spectacles into their case. Then if you look at the legs of the crab, you will see how beautifully they all fold up close against its body. You should look, too, at the mouth of the crab, and you will see a very singular thing. I cannot go into the particulars; but at the outside of all you will see two pieces like double doors, which fold over and cover the inner parts quite close; and then the great claws, if put where they would naturally be when the creature is at rest, securely bar

the doors of the mouth, and keep everything fast. If you come to think where the crab lives, you will see how desirable it is that these things should be as I have said. The crab lives in the sea where there is a stony bottom, and at some little distance below low water mark, but within reach of the rough weather, and is liable to be tossed about very much. Well, it can pack itself up in the way I have mentioned, and may then be rolled over and over just like a boulder stone, and take as little harm. You see, therefore, in the case of the common crab, how well fitted it is for the circumstances in which it is placed. It has a sort of confidence in the strength of its armour too, and goes about like one of the knights of the middle ages, seeking for some one to attack. But the crab is much better protected than any knights ever were in their armour; and besides this, the crabs are their own army surgeons; they need no splints, bandages, nor lint. If they have the misfortune to have a piece of a limb snapped off in an encounter, they just give that leg a shake and off it comes at a spot almost close to the body, where nature has provided that these voluntary amputations shall take place; the bleeding stops, and the crab is at once ready to go again into the fight.

One day I found a crab at Llandudno, that had lost both its claws and all its legs but two; yet, for all that, it had not lost its courage. I picked it up, and, at the same time, selected another crab of its own size, and put them together in a dish filled with sea water. It was pretty to see how the brave little fellow, without any means whatever of attack, still stood on his defence; for that perfect crab, more shame to him!—crabs have no magnanimity—at once picked a quarrel with his unfortunate brother, and attacked him savagely. My crab stood bravely up, and defended himself as well as he could. Now, how did it happen that a crab in this miserable state should never think of giving in? Well, I think it is that the crab still feels that although so defenceless, he has the capabilities of a warrior left in him; he feels, perhaps, that his fresh legs and arms are already sprouting where the old ones are gone, and that if he could only be let alone for a time, he would have new claws and legs, and be able to give as good as he took. Now, the crab can really afford to be reckless in battle, although it is not invulnerable, for nature does repair its shattered limbs as often as it is required. The brave little fellow I have been telling you of, if he could only have been put into hospital for a time, would have come out as good as new, with all his claws and legs complete, and with no need for such tender nursing as our wounded soldiers received in the Crimea from Miss Nightingale

and the Sisters of Mercy. And, after all, the result is far more satisfactory in the case of the crabs, for with them you see no crutches or wooden legs—nothing of that kind; they come out bran new, and as good as at first. Perhaps, if you consider this carefully, you will be led to suspect that nature did not design men with a view to their fighting in the destructive way which is now practised by civilized nations.

But although the crab is so well provided in the matters I have mentioned, seasons of great anxiety come upon him now and then, and these are when in consequence of his constant fighting and feasting he feels he is growing too stout for his shell; he feels that his trusty armour on which he had depended so long is getting too tight for him! At last the dreaded moment comes when he can endure the pressure no longer, though he knows at the same time that his safety, if not his very life, depends upon his coat of mail. Still he feels at last he *must* throw it off and expose himself defenceless to his enemies. Here you would think would be a time for serious reflections upon his past career of riot and barbarity! But instead of thinking of repentance, this crab crouches in some dark hole trembling for his safety, and anxiously hoping that his new suit will soon be ready. His fears are probably heightened by a guilty conscience, for he feels within himself what he would have done in his strength if he could only have had the luck to meet with a defenceless soft crab, such as he is at that time! Oh! what a juicy meal he would make of that crab! Well, thinking so, he naturally trembles for his safety. I once brought home with me two little crabs from Blackpool, and I put them into some sea water with sand, and fed them regularly, so that I kept them alive for some time. When I had had these two little crabs for about a month, one of them cast his shell. The other one, as it happened, perhaps in consequence of being well fed, did not molest this crab while it was soft, and in a few days it came out again as brave as ever. Shortly afterwards it came to be the other crab's turn to cast its shell, and then the ingratitude of that wretch was at once seen. No sooner did this second crab cast his shell than he rushed at him and ate him up! I am happy to say, however, that it was not many days before justice overtook him, and he died, either from a bad conscience, or—what is perhaps more likely—indigestion.

Now, we will leave these sea creatures which breathe by gills, and pass on to some of those which live on land and breathe air. I shall therefore have next to speak of insects. In all insects you find there is a concentration of the organs of locomotion

about equal to that which you notice in the lobster. Insects have a body divided into three parts, and the legs are always attached to the middle part; and they are moved by strong muscles which are contained within that middle part of the body. These legs of insects are very active, and are used for a great many different purposes, as for creeping, running, jumping, and swimming; and they are modified to suit the requirements of the insects in all these different ways. Most insects have wings as well as legs, but there are some which are always without wings—for instance, the flea; but this flea, you know—I dare say you know—has the power of jumping in such a way as to be almost equal to the power of flying. I confess I can never see one twice; if I see it once, I cannot see where it goes to. But just consider for a moment if you were endowed with the same power of jumping, in proportion to your size, as the flea, and you jumped, the result would be fatal, for you would come down with such a crash that you would break every bone in your body; so that it is lucky for us that we have not the powers possessed by some of these insects.

In an animal which has the power of flight, it is necessary that the body should be very light, and that the muscles which move the wings should be very powerful, and, at the same time, very rapid in their action. These two requisites are brought about by one and the same simple means in insect structure, and it is in the arrangement of the breathing apparatus. Breathing is like a draft of air going through a fire, the more perfect the draft, the more rapid will be the burning. We have seen that in crabs the gills receive the blood from the legs and claws, charged with the waste matters from muscular action, and purify it from these things, taking in oxygen at the same time from the water; but this aërated blood in the crabs is mixed in the heart with impure blood, which comes from the other parts of the body, and so returns to the muscles, to act on them, in a state which is not stimulating enough to produce very energetic action. The plan which we have in insects is quite different, and is not seen in any other part of creation excepting in them; it is beautiful in its simplicity. The blood of the insect is not contained in vessels at all, but freely fills every part of the body not occupied by something else. In this way it bathes the whole surface of the internal organs and of the muscles. But you find in every part of the insect air-tubes, which I shall show you with the lantern from a drawing of the anatomy of one of these insects. You see in that drawing a great number of little branches going in all directions through the body of the

insect, and these might be thought to be blood-vessels; but they all contain air, and if you look carefully at the drawing, you will see that here and there there are large dark-coloured places which are reservoirs for air. If you trace those branches to their origins, you will find that they arise from certain points down each side of the body, and in the perfect insect there are holes from the outside, where the large trunks of these air-tubes commence, and through which the air is admitted into the interior of the body. These holes you will find are often beautifully fringed with hairs, the object of which is to prevent dust from getting in. By this plan of conveying air to all parts of the body of the insect, instead of carrying the blood to the lungs or gills to be purified, you get an extreme lightness of the body, and at the same time you have the most perfect possible aëration of the blood. This perfectly aërated state of the blood, and its free and direct contact with the muscles, produces their energetic action. As examples of flying insects, I have chosen butterflies as being very common, and some of these I will put on the screen. These butterflies may not be very remarkable for perfection of flight, but they show large and beautifully coloured wings, which is the subject about which I want to speak. There are, however, many kinds of butterflies, which are not to be despised on account of their small powers of flight, and entomologists will tell you that some are very hard to catch, and will outfly their best efforts at running. The butterfly is provided with a kind of long trunk, with which it sucks out the sweet juices from flowers, and this is what the butterfly feeds upon; but you must not for a moment think that it is the honey from the flowers which has developed the powerful muscles which work those wings, and the wings themselves of the creature. Those butterflies originally came out of the egg, as you know, in a very different state from that in which you now see them. They were then little greedy grubs, which went about, day after day, doing nothing but eat; they were eating constantly, as though their very life depended on getting down as much vegetable substance as they could possibly swallow. This was the way the caterpillar or grub of the butterfly went on for a long time, and during that period he had frequently to change his skin, on account of its getting too tight. Now, if you traced him through his career, you would find that at last there came a time when he cast his skin, and instead of coming out as a caterpillar, he came out as something quite different; he came out like a mummy, with a hard case about him, being what we know very well as a chrysalis. His limbs were gone, his power of eating was gone, and there he

lay for a considerable time helpless. He showed his care for himself just before he went into this state, however, by, in some cases, hanging himself up in a convenient corner, or, in others, burying himself in the ground, where he remained for a considerable time, until at last he burst from that chrysalis form, and came out a perfect butterfly. You see, then, in tracing the history of this creature, that the real nutriment which produced those wings and that powerful flight was that which was taken when the creature had no wings at all. It kept storing up nourishment for weeks and months, not for its own immediate use, but for future purposes. In that representation of the caterpillar, you will see down each side of the body masses of substance looking like suet or fat in the living creature. Down the middle you see the alimentary canal through which the food passes. Independent of the proper organs of the caterpillar, then, you see immense quantities of fatty material which is stored up for the future making of the butterfly. While the creature is in the chrysalis state, all the substance of its body seems to go soft and milky, and it looks as if it were made over again; created afresh, on a larger scale, and in a more perfect form, by using up the hoarded material which had taken months to collect in the caterpillar state. You see, then, I think, from this how difficult it is to make a flying insect; how for months the creature must go about as a grub, and do nothing but feed, in order to store up an abundant supply of material to make this beautiful flying creature. Then, the butterfly exists but for a short time, and perhaps it could not possibly support itself for long by the nutriment it is then able to take.

Leaving the butterfly, I shall now give you an example of the most perfect of flying insects—the dragon fly. This creature is well worth careful examination by those who are interested in locomotion as a mechanical matter. There is nothing more perfect in nature than the dragon fly, and if you look at it, I think you will say after my explanation, that the comparison of it to a railway train is not far-fetched. The part to which the wings are attached is the engine with its four driving wheels. Here you see the head which we may naturally call the guard's van, placed in front to keep a good look out; and behind you have the carriages set in a row, and not concerned at all in producing locomotion, as I showed you that all the joints in the centipede are. This dragon fly has most wonderful powers of flight. It has been watched when chased by a swallow, which is a very quick flying bird, and the swallow has not been able to catch it. The dragon fly, different from other flying creatures, can not only fly forwards with great

speed, but without changing its position apparently, it can fly backwards, and it can also fly to the right or to the left, and up and down, with the greatest facility. Let our mechanics just consider that, and see if they could make a working model of the dragon fly.

In my next lecture I shall bring before your notice creatures which show chiefly the development of the internal organs of the body, those of digestion and secretion. They consist of shellfish, and I shall chiefly have to speak of oysters, mussels, cockles, and creatures of that kind.

ZOOLOGY,

OR

FOUR PLANS OF ANIMAL CREATION.

LECTURE IV.

FOURTH PLAN.—SOFT-BODIED ANIMALS—DIGESTIVE AND SECRETING ORGANS.

BODY consists of a bag containing organs for digestion and secretion. Ascidia or "Sea Squirt." Description. Nature of its food and manner in which it is obtained. The same organ for breathing and for collecting and conveying food to the stomach.—Bivalve Shell-fish, general character; breathing and feeding associated.—The Oyster, description of the animal, formation of the shell.—The Freshwater Mussel, description; means of locomotion, the foot: habits. Artificial pearls, and pearl ornaments made by the Chinese. The Freshwater Pearl Mussel of North Wales. The Common Mussel, structure of the foot, and manner of making the threads by which it fixes itself. Parasitic Crabs found in Mussels. The Dreissena, a foreign Freshwater Mussel now common in canals. Manner of making its threads easily watched in an aquarium.—Common Cockle, description of the animal, form of the foot and its use.—Mactra, Venus, Tellina, and Donax, pretty shells, commonly found on the sea-shore. Description of the animal; these, like all other sea creatures, should be taken alive and put into sea water to be watched.—Razor-shell. Structure of the animal: habits. Pholas common at Blackpool: habits. Peculiarity about the dead shells found on the shores of Lancashire.—The Teredo, or Ship-worm, description.—Conclusion.

If we take our own body as an example of animal structure, we shall find that it consists of two parts; first, there is the framework to which it owes its form, and which provides for locomotion, and for all we can do in relation to the world outside; and secondly, there is a set of internal organs, the duty of which is to nourish and continually renew the working muscular frame. In my last lecture I explained to you the structure of jointed animals, and I showed you that through all the extensive series of forms which they present, the motive framework is made a matter of first importance, and that in some flying insects, as the butterflies, this is carried to such an extreme that provision is not made for keeping up the full nourishment of the body, and consequently that the creature can only live a short time to enjoy its power of flight. To-night I shall have to speak of animals formed upon quite an opposite plan, for they consist of very little beside internal organs. The lowest of them may be described as nothing more than a "bag of bowels," and even the highest have only very faint traces of a hard framework connected with such muscular apparatus as they possess for locomotion. These animals are called "mollusca," and are commonly known as "shell-fish." They include not only all kinds of sea and fresh water shell-fish, but also land snails and slugs.

The first example of mollusca that I shall give you is one of the lowest and simplest of all of them, and it is called the "Sea Squirt." I will show you a diagram of this creature upon the screen. You might suppose when you look at it that I had been borrowing a double-necked bottle from my friend, Professor Roscoe. You are aware, I dare say, that the two-necked bottles are very important parts of chemical apparatus, their value, I believe, consisting in the fact that there is one way into them and another way out; and that is precisely the case with the creature before you, which has, as you see, two openings into the cavity of its bottle-shaped body. The way into it is by the hole at the top of the creature, and the way out by that at the side. This sea squirt may be found upon any of our shores, fixed to sea weeds, which have been torn away from the sea bottom and thrown upon the beach. At Beaumaris you can find them in plenty, and there are some very small and beautifully transparent kinds which give you a good opportunity of watching them under the microscope in the living state. If you look at the diagram farthest from me, you will see this creature partly dissected. When you cut open a sea squirt you find that connected with the opening at the top, there is a thin delicate bag which fills a good part of the inside of

the animal, hangs free from the outer walls of it, but passes down to the bottom, and there opens by a small aperture into the stomach of the creature.

I showed you in my second lecture that the hydra is a fishing animal, and that it catches its food by means of a rod and line. This sea squirt is a fishing animal too, but it catches its food by means of a net, and the bag I have been speaking of contained in the inside of the creature, is the net with which it catches the animalcules that serve it for food. The net is covered on the inside all over with vibrating hairs, and these produce a strong current of water from the outside into the net through the upper opening, and the water brings along with it all the minute living creatures that happen to be in it. The water is filtered as it were through this net, and passes out at the side opening, while all the solid food is retained, slowly passes down to the lower part, and at last enters the aperture which leads to the stomach. In this sea squirt you have something that is worth your notice, as a contrast to what we find in the crustacea. We find there that the gills or breathing apparatus are in close connection with the legs or organs of locomotion. Here we find that that net or bag which I have been speaking to you about, is not only the organ for taking food, but is also a gill and serves for respiration. Respiration then in these soft bodied animals is associated with feeding. If you look closely into that fact you will see that it contains an important truth, namely, that the breathing which always corresponds with waste of living materials of the body, and in crustacea is regulated to the amount of muscular waste, here corresponds with waste of some other kind, and that will be found to be such as arises from the chemical changes necessary for the production of various secretions. The creature that I have shown you is perfectly stationary, and has no need for any further muscular power than to contract or expand the bag of which the body is composed; but it is a sort of chemical laboratory in which a great deal of work is done in a quiet unobtrusive way. I may just add that it is called the sea squirt for the simple reason that when you lay hold of it, it throws water out from the two holes with which it is provided.

Now this very simple plan of animal structure that I have been bringing before you is repeated in endless variations through the whole class of mollusca or shellfish, and the number of different kinds is so great that they form one of the principal divisions of the animal kingdom.

An important addition, however, is generally made to what you saw in the sea squirt, and this is a hard case for protection, which

is placed on the outside of that soft body. This hard case is what is commonly known as the shell; but you will see at once that if the sea squirt were entirely covered with a hard shell it would be so closed up that it would be impossible for it to grow larger. Two plans are adopted among the shellfish for obviating this difficulty. The plan which I shall show you first is a very simple one, namely, to cut the outer case into two halves, each covered with a shell which can grow larger to any extent at the cut edges. This is the arrangement in all the common bivalve shells and you see it very clearly in the oyster, which I will now show you on the screen. That is a representation of the animal in the inside of the shells. One half of the "mantle," or outer case, with its shell has been removed, and you see only the other half of it. Inside you see the bag of viscera which composes the body of the animal. Now, if you look at the oyster when in a living state, you will see that the shells keep open, and that currents of water continually enter through the opening of the shells, pass over the interior of the soft part of the mantle, and then pass out again. If you look at the animal itself you will see the gills, looking like leaves of a book placed between covers, which are represented by the shells. These gills, which correspond with the inner bag or net in the sea squirt, are covered with vibrating hairs, producing currents just in the same way, and carrying in the animalcules upon which this creature feeds. All bivalve shell-fish feed entirely upon minute water animalcules.

The shell of the oyster is formed in a very simple way, by the outermost coat of the animal depositing carbonate of lime, and so producing a very thin film of hard shell material. When that is formed, another thin layer forms in the inside of the first, and extends a little beyond its edges; then another forms, and another, and in that way the creature covers itself with protecting shells which are continually becoming larger and stronger as they grow. The two shells of the oyster, as well as of all other bivalves, are kept gaping open by the nature of the substance by which they are attached together at the hinge. This substance is elastic, and springs the two shells open, and that is the natural state in which the animal always is, because it can then draw in the currents of water by which it both breathes and feeds. But sometimes it wants to shut its shells, and in order to do this a strong muscle is provided which passes directly from one shell to the other in the inside, as you doubtless know very well, since you must have seen it in opening oysters. This muscle shuts the shells when necessary; but it no sooner

relaxes than they come open of their own accord, and the animal is at liberty to feed. As to the animal itself, I should remark that round the borders of the mantle are a number of little coloured spots, which are eyes. You might naturally suppose the creature would want to see, in order to know what was coming in between the shells along with the water; and as an intruder might enter at any part, these eyes are set at intervals like a row of sentinels. I would have you remember, then, the next time you eat oysters, that when you open the creature in the murderous way in which the work is done, the animal is looking on with all these eyes, which perhaps may not be a pleasant reflection for you!

Leaving the oyster, I shall now speak a little about the common sea mussel. In this case you have a creature of a different shape from the oyster—long-shaped instead of being rounded in outline; and corresponding with this you find that there are two muscles passing across from one shell to the other to close them when the animal wishes to do so. I will now show you a mussel, and the thing I want to direct your attention to is a part of the animal which you see projecting from between the shells. It is called the "foot," and is a long and slender muscular organ, which in the living state can be extended to as much as an inch and a half or two inches in length. This foot in the mussel is used for producing those threads by which it fixes itself; and it is perfectly easy to see the creature make the threads. If you take some mussels and put them in sea water, the first thing some of them will do will be to anchor themselves by these cords. The way in which the foot is used is this: it has on one side a deep groove running from one end to the other. At the part next to the body of the animal, there is a gland which secretes a sort of liquid silk. The creature puts out its foot as far as it can, and feels about for a suitable place where to fix a thread; then putting the end of the foot firmly against the stone, or whatever the object is which it has selected, it forms the groove into a tube by making its edges meet, and then, by pressure on the gland, fills the tube with the liquid cement, holds all still for about a minute, then relaxes the sides of the groove, and withdraws the foot, and a strong thread remains attached by one end to the stone, and by the other to the body of the animal. In this way the mussel forms a number of threads, which hold it firmly in its place. In the mussel, the water does not enter between the shells so freely as it does in the oyster, for in the living animal the edges of the two halves of the mantle are kept in contact, except at two places where openings are left for the currents to pass in and out. The larger of these openings,

where, as you see, the edges of the mantle form beautiful frills, is the one through which the water is drawn in, and the smaller opening placed nearer to the hinge of the shell is that through which it escapes. You may find mussels growing on many parts of the sea coast; you can see them perhaps as well as anywhere at Morecambe. There you find the whole of the shingly beach matted over with these shell-fish, living among the stones, and there is a stone pier on the shore with mussels completely covering its sides up to extreme high water mark. It is remarkable that mussels can live in such a position, since they must be entirely out of the water for by far the greatest part of each 24 hours. This is so remarkably the case with the mussels that in some instances they are found living so high that only the spring tides can reach them—that is, twice in a month for two or three days, and they live the whole of the intervening time with no fresh access to the sea water. This has been explained, or attempted to be explained, by the fact that when the water goes from them they retain their shells full, and that the animalcules which were in that water breed and reproduce to such an extent that during the interval they supply food for the mussel.

I shall now show you a little parasite which is very commonly found in the mussel; I dare say some of you may often have met with them in mussels used for food. Here is a rough sketch of my own, taken from life. The mussel was one which I got alive from the sea coast. I had several of them, and when put into sea water each of them was found to contain a little crab. The crab is well known as a parasite in shellfish. You see it there in its natural position. It is formed for living in shellfish, and it has not accidently got in there. As you see it on the screen, you notice that it has fixed itself just at the part where the water goes into the mussel to feed it; and it holds its claws ready to lay hold of anything sufficiently large to serve for its food, and which might come in with the current of water into the body of the mussel. You will see then that this little crab ought not to be called a parasite, in the sense of its being injurious to the mussel; it is quite the contrary, for it seizes anything that would be too large for the mussel to use as food, and so protects it from creatures which might injure it. In our canals all over this neighbourhood, you may find a shellfish very much like the sea mussel: it is called the dreissena. It is a shell which came over from the Baltic, it is supposed, in timber vessels, by which means it got introduced into the docks and canals of this country, and it spread to such an extent that now very few of our canals are without it. I may mention

that the Beswick reservoir, now done away with, had its sides completely paved with these dreissenas, or fresh-water mussels. These are very capital things to have in a fresh water aquarium, and you may see them make those threads for anchoring themselves, which they do in the same way as the sea mussel, without any trouble at all. They are also very useful in the aquarium because they do what all other bivalve shellfish do—they filter the water from its impurities; and they remain fixed in one place, which is another advantage.

I shall now show you another fresh water bivalve, very common in this neighbourhood—the common pond mussel. In this case there is a very large foot, which is the most remarkable part in this shellfish. It is composed of interlaced muscular fibres passing in various directions, and it comes out looking like a cow's tongue. The object of this foot is more for the creature to bury itself in the mud than to go from place to place. It does use it for locomotion, but its great object is that having found a suitable place it can fix itself there. This mussel, being of a good large size, has a great deal more filtering power than the dreissena, and in the aquarium it is very useful, as you may test at any time for yourselves. If the water of an aquarium when newly set up remains muddy, as it generally does, you will find that by putting in one of these large mussels you will get it as clear as possible in a few hours; so that it well deserves the name of a "living filter." I got one of these pond mussels of the largest size from the lake at Lymm, where they are very abundant, and kept it for two years in a small jar of water only just large enough to hold it, and the creature had nothing but a small quantity of our excellent town's water as its food for the whole of those two years. You know, as I explained in my first lecture, there are no animalcules in our town's water, and yet this pond mussel of mine had nothing else supplied to it for two years. Now there is something curious about that, but I think you can explain it from what I have already said. The water was changed about once a week or fortnight, but during the time the mussel remained in it, you must bear in mind that myriads of animalcules would be developed, and these served it for food. You have here then a parallel case to that of the sea mussels which live at extreme high water mark.

These common fresh-water mussels might be used for making artificial pearls. At different times a good deal has been thought on this subject. It is perfectly easy to make them, that is, to make the animals make them. If you put grains of sand and other extraneous matters between the soft part of the animal and

the shell, the irritation caused by them produces a deposit of carbonate of lime upon those extraneous matters and the concretions become larger by fresh layers being added in a concentric manner, until they form very tolerable pearls. The Chinese have carried out this notion to a very great extent, and constantly make little ornaments of pearl by taking advantage of this property of their common fresh water mussel. They have little images made of wax, or something of that kind, which they push in between the soft part of the animal and the shell, and they will make as many as a score of these pearl ornaments on one single shell. We have in this country a kind of fresh water mussel which naturally produces pearls. It is found in the river Conway, in North Wales, and in the Lune, and other rivers in that district. This mussel is found in rapid streams which run a short course from the mountains. These streams are sufficiently rapid to carry along with the water both sand and fine gravel, and I think the reason why pearls are found in this kind of mussel is that extraneous matters frequently gain entrance into the shells, and, causing irritation, lead to their production.

I must now leave these animals and say a word or two about cockles. I have a cockle represented there in a picture. When people cry "cockles" in the street, you always hear them say "cockles *alive!*" as though it were a great recommendation, as indeed it is. But I very much doubt if many of you have seen cockles alive. If you will dig up some of them from the shore for yourselves, and put them into sea water, then you will see your cockles alive, and you will find them something worth looking at. You will see that by and by they put out a couple of tubes like those represented in the drawing, and the tubes are ornamented with a number of little tentacles or feelers. Now, if you watch those feelers closely, you will see that those on the edge of the tube through which the water enters are each provided at their tip with a bright and beautiful little eye, the use of which is evidently to see what is coming in. Cockles are so abundant that I scarcely need to mention particular places where they are found. On any sandy coast you may find them in plenty. At Blackpool there is a great abundance of them, and to show you their prodigious numbers I may say that in a space of four inches square I have myself picked out a dozen fair-sized cockles. At Southport you know they are so abundant that it is said they are occasionally sent away by tons at a time. These cockles have short siphons or tubes by which the water enters and passes out, while in the mussel, as you saw, there was nothing you could call

a tube at all. The foot in the cockle is a remarkable part of the animal. If you see the whole of it you will find that it is bent in the middle like an elbow. Though the cockle as a rule uses its foot to bury itself, it can jump by means of this foot, springing up in the air, and so moving itself to a considerable distance. There are several kinds of fresh water shells something of the nature of cockles which are worth saying a word or two about. They are found in all the ponds and canals in this neighbourhood—little bivalve shells, not half the size of the cockle, but interesting, as having the same kind of structure, and they are within our reach to watch them closely in our aquariums at home. They are called Sphærium. There is one kind which was found about five years ago by Mr. Darbishire in this neighbourhood, and which is not known at the present time to exist in any other part of the country than in the Manchester district. I have received it very fine from Accrington, and I have also found it in the Peak Forest Canal. This, which is called Sphærium pallidum, is an American shell, and is supposed to have been introduced in the vessels which are constantly going and returning from that country. There are other shells nearly like these, but so small as to be scarcely larger than a pin's head. These are found in ditches, about the borders of fields, everywhere in this neighbourhood, and they are interesting as showing the fulness and completeness of creation, for their presence in these miniature collections of water looks as though Nature were determined to occupy with living creatures every nook and corner where they can possibly exist.

I must now pass to some shells which are distinguished from the cockles by very long siphons. I will show you one on the screen. These shells include most of those pretty kinds that people pick up on the sea shore for the sake of their beauty. You may find plenty of them at Southport, but they are almost always dead. On the beach at Penmaenmawr you may find these shells in plenty. You will notice in this case that the siphons or tubes through which the water passes in and out are very long; these creatures have the same habit as the other bivalves I have mentioned of burying themselves, but they plant themselves deeper than those with short tubes do, and only have a part of their siphons projecting above the surface. In this way they are safer from their enemies. The water passes in through the tube nearest to the foot, and out in a constant stream at the one nearest to the hinge of the shell. That, as it is shown on the screen, is the natural position in which the creature lives, with the tubes upwards. There is one kind of shell with these long siphons that

you get in plenty at Southport buried in the sand. You may find it by its leaving a little groove on the surface. If you dig at one end of that groove you will be sure to find a living shell-fish. It is called tellina solidula. If you take some of them home and put them in sea water, although the shells are not more than three-fourths of an inch in diameter, they will put out siphons as much as two or three inches long, and they really are worth examination. The way in which these siphons feel about as it were, to get the best water for their purposes and to avoid anything injurious, is very curious. I should say, then, that when you find any of these beautiful shellfish alive, you should always increase your pleasure by taking them home and putting them in sea water, then you can watch them and observe their mode of life before you kill them for the purpose of keeping. Talking of this subject, I may mention that I was once walking on the sea shore, when I saw near to me a lady and her little boy, who were picking up shells by way of amusement. By and by, the boy, who seemed in high glee, picked up a shell and came running to show it; but the lady no sooner saw it than she exclaimed in horror and disgust—"O you disagreeable child, throw it down, don't you see it is alive?" Now it struck me at the time that this was not the way to instil a love of nature into the child's mind, nor was it the way to obtain all the interest and pleasure which might have been derived from the opportunities that were then at hand.

I shall show you one other burying bivalve, which is called the "razor-shell." You find these by thousands and thousands on the shore at Southport, but you almost always find them dead and empty. You have a representation there of both the shell and the animal. At the lower part of the animal is a foot, which is very large and strong, and is used like a spade or digging implement. The upper part, that which is cross-barred, is the gills. At the top are two openings through which the water passes in and out. In that way there is a regular circulation of water through the upper half of the animal; the lower half is occupied entirely by the foot. This razor-shell buries itself deep down in the sand; it will go down to the depth of a foot or more below the surface of the sand. These razor-shells may be found living at extreme low water mark, and in consequence of their burying themselves to a considerable depth, it is only after a storm that they are disturbed and thrown upon the shore. The reason you find them always empty when lying about the sand, is that when thrown out by the sea, the birds come at once and take out the meat, and a tempest is therefore a rich harvest for them. There is a shell at Blackpool that is

of a good deal of interest, and I mention this locality because, although it is found all along the Lancashire coast, I know no other place where you can so easily find it alive and in its natural state. It is called Pholas Candida. A place where it may be seen is about half way between Blackpool and Southshore. You may notice there on the sand, and projecting above it, a mass of firm black peat. If you look closely at this, you will see that it is the remains of an ancient forest. There are about a dozen stumps of trees imbedded in it, and the rest consists of vegetable matter hard pressed together amongst the roots of these trees. At the lowest edge of this mass you will see great numbers of holes in the upper surface, and these are occupied by the pholas animals, which bore the holes to live in. I mention this spot particularly, because with your knife or any simple tool you can easily break away a piece of this material with the living shellfish in it, and take it home, put it all together in sea water, and see the things in their natural state. The place at Blackpool, however, where these shellfishes live in numbers is lower down in a bed of clay, which you can see extending as far as the tide goes out. There, at low water, you may walk over acres of this clay riddled through by the pholas, and they present really a very curious sight. The waves come in there over this flat bed of clay like a great planing machine, and keep wearing the clay lower and lower, but slowly, because the clay is very stiff and firm. As it wears away, the pholas animals are gradually laid bare in their holes, and when that happens they die. Young pholases, however, begin life afresh and go down deeper into the clay, so that you may see at any time there a very singular thing, which does not happen with ourselves, namely, a great cemetery or burial ground of dead pholas on the surface, while all the living generation are buried below.

The next bivalve I shall speak of is the Teredo, or ship-worm, a very formidable plague to wooden ships. It eats into the wood, feeds upon the wood, in fact, and bores passages in all directions through it, so as to make it completely worthless. I will show you the animal on the screen. There are two shells at the lowest part of the animal, then the siphons or tubes form the long soft part, and have an appearance very much like a worm, which has given the name of ship-worm to this creature; it is, however, a bivalve shell. This teredo, though it is such a pest to wood-work exposed to the sea, has done one trifling good service, and that is, it is said to have suggested to Brunel the plan of tunnelling which was used by him in making the Thames Tunnel, and that I believe is all the good that can be said of it.

Leaving the bivalves, I shall now say one or two words about the other mollusca. I told you that in order to obviate the difficulty of putting a hard case upon the bag of viscera which forms the chief part of the body of all shellfish, the mantle or outer fleshy covering in the bivalves is split into two halves. In the univalves of which I have now to speak, another kind of provision is made for continuous growth, which is done by cutting away one end of the mantle, so that the animal is at liberty to grow in that direction, and consequently the univalves have always the cone shape which you see most evidently in the common limpet. The univalves differ from the bivalves in this also, that the foot does not stand out like a tongue, but is a flat disc upon which the creature can walk with a sort of gliding motion; and they have a projecting head with a mouth and organs of sense, as sight and touch, because they go in search of food and select what suits them. There is a remarkable thing in the univalve shellfish, and that is that they have in their mouth a very peculiar kind of tongue, an organ for taking their food, and this is in the form of a long strap, the upper surface of which is covered over with little hard teeth, set in transverse rows. The front part of this long strap goes into the mouth, and there curves over a hard cushion, so that there is a curved surface able to be pushed out from the opening of the mouth, and the teeth over that curved part stand out like the teeth of a saw, or a half round rasp. By this means these univalve shellfish rasp the food which they take into their mouth. There are a great many kinds of univalve mollusca, but I must only mention one or two; there are snails and slugs for instance, with which you are all very familiar. Most people think of snails only as being injurious in gardens; but our neighbours on the continent find them good to eat. There is one kind found in our southern counties which is called the "edible snail," and it is called so, as Forbes remarks, not because it is better for food than the other kinds, but because there is more of it. It does not appear, however, that even these large ones can tempt us to try such delicacies in this country. The slugs, or snails without shells, are a great plague to gardeners, but there is one kind of them that deserves a word of commendation, because it does not eat vegetable matter, but feeds upon worms. This slug is called testacella. It is found in some parts of this country, but appears to have been introduced from abroad; it is chiefly found in nursery gardens. It is a very curious little creature, and has on the very tip of its tail a little shell placed there like a shield; the wisdom of which provision is at once evident when you remember that the creature feeds on worms and goes down into the worm-

holes in order to find them. But for this shield upon its tail, it would be in danger of being eaten up from behind by another of these worm-eaters on the same errand as itself, and this little shell is therefore of great use to the creature by guarding it in the rear.

The common limpet deserves a word of notice. It has a simple cone-shaped shell. It is found on every exposed sea-coast sticking to the rocks, and its shape is beautifully adapted for resisting the force of the waves. At low water at Puffin Island, you may find some very good illustrations of the limpet. Where the sea is very rough, there you find the cone of the limpet is flatter; the limpets there wear the limestone rock into pits just of the same shape and size as the base of their shell, so that no amount of side force can possibly dislodge them. They are good illustrations of the conical shape which all univalve shells have. Generally, however, the cone is not straight, as in this case, but twisted like a corkscrew, as you see in the common whelk. If you could open this whelk-shell and make it straight, you would see it then as a long cone; but by being twisted in this way, the shell is made not only more compact but much stronger. The whelk is an animal-feeder. It can put out at its mouth a long trunk in which is contained one of those peculiar strap-shaped rasps of which I have spoken, and which it uses for perforating bivalve shells in order to get at the animal within. It bores a neat round hole into a shell, such as you often see in shells lying on the shore, then puts in its long trunk and extracts the meat.

The highest of all the mollusca are the cuttle fishes, of which we have an example in this painting of the common octopus. None of our British kinds have any outside shell for protection. They are very remarkable looking creatures; the body is shaped like a bag, and there are two great eyes, which give them an intelligent expression, causing you to pity them when you see them lying helpless on the shore. Round the mouth are eight or ten long arms. These arms are covered on their front surface with suckers by which they are able to lay fast hold of anything they wish to take as food. The mouth itself is provided with beaks, like the beak of a parrot, and if anything is once laid hold of by these suckers and drawn to the mouth, its escape is impossible. At Llandudno, I have caught as many as half-a-dozen large cuttle fishes, which had been thrown upon the beach, and I had many opportunities of watching them. If one is put into a pool on the shore you will see it swim by a sort of rowing motion of its arms; if, however, you tease it, as I am sorry to say I did with a walking stick, it adopts a different plan of locomotion; and this plan is to make use of the water which is alternately taken in and

expelled in breathing. The gills of the cuttle fish are placed on each side of the body, and are lodged in two pockets. The water is drawn into these pockets by their expansion, and is expelled, when they contract, through a tube on the under side of the body, and this tube having its opening directed forwards causes the animal, when the water is driven from it very rapidly, to shoot backwards with great force. I have seen one, when angry, shoot backwards in this way with such force as to throw itself completely out of the water. Sometimes in addition to this mode of swimming they adopt another means of escaping danger, and that is, they throw a quantity of black ink, which is a peculiar secretion of the cuttle fish, and so leave a dark cloud behind them under cover of which they can easily escape from an enemy in the water.

I have now brought before you, in these four lectures, four different plans of animal structure which are observed in the lower animals, or those included in the invertebrate division of the animal kingdom. The first plan showed us that life may exist in matter independent of any organization at all. The second plan showed that the stomach, whose duty it is to provide material for growth, is the most important organ. The third plan showed an infinite variety of designs for locomotion, all worked out from the same original type of structure, and presenting to the eye of the mechanic every conceivable plan and contrivance for effecting that object, and all to be seen in perfect working order. And the fourth plan, the one that I have brought before your notice to-night, where the body consists of a bag of soft organs; the illustrations of which are perhaps chiefly interesting and valuable on account of the endless forms presented by the protecting shells. These shells, being uniformly hard and strong in their texture, will give to the intelligent engineer the most perfect and suitable illustrations of the exact form required in each instance to gain the greatest strength with the smallest quantity of material for various purposes to which cast-iron can be applied. It is strange that those whose business it is to create—for all machines and engineering works are creations—appear to have generally neglected these perfect models, and worked out with infinite mental labour, and great waste of time and money in blundering, the very same ideas that are clearly and exactly illustrated over and over again in the natural world. It is not, however, within the province of the naturalist to do more than try to have it understood by those concerned, that all animated nature is full of hints for perfecting existing mechanical contrivances, and of suggestions for inventions not yet even thought of, which may promote the comfort, convenience, and happiness of mankind.

ON COAL.

PROFESSOR ROSCOE, who presided, introduced the lecturer, and stated that his subject would be "Coal, its economical value, and its importance in the arts and sciences." Professor Roscoe added that the lecturer had made a special study of the subject of coal, and had published a book which had attracted great and deserved attention from scientific men, manufacturers, and the Government, and had led to the appointment of a Royal Commission for inquiring into the subject of coal, the amount of its consumption, its probable duration, &c.

Professor JEVONS explained that his remarks would be a continuation of what Dr. Roscoe had told them in his lectures about coal, its numerous uses, and the great power evolved from it by its conversion into heat and motion. Perhaps, continued Professor Jevons, the best way of showing you what coal does for us is to enumerate a few of the principal uses of coal as we apply it. First of all is its domestic use. We use it for warming our dwellings and for cooking. I think that during the present severe weather nobody will mistake the value of coal in warming our houses. I see a great number of carts of coal going about the streets—everybody seems to be trying to get a good supply; but Dr. Roscoe tells me that his coal cellar is empty, much to his inconvenience. I am afraid that a great many others may be in that unfortunate position, with the thermometer near zero. I will give you an idea how much coal is used for domestic purposes. According to the common estimate, the average consumption of coal for each person annually is one ton, which would make about 30,000,000 tons per annum, in the United Kingdom. It is obvious that we should not know what to do without coal, for there is not timber enough in the country to supply the fires. If we burnt wood, we should need to plant nearly the whole of the

country with trees. In France wood is still used as fuel, and much valuable land has to be given up to the growth of forest trees. Even in the United States, which used to be considered an inexhaustible country, the scarcity of wood is becoming felt in some parts, and the Washington government has recommended the planting of trees in some of the states. But the domestic use of coal constitutes a small part of its utility. The next use I may mention is in the working of the metals—for instance, in the blacksmith's forge. From the earliest times coal seems to have been used for the blacksmith's fire. It is peculiarly suitable for making that sort of "breeze" or small coal which is necessary for the blacksmith. It is very probable that the abundance of coal in Staffordshire and Yorkshire assisted in the formation of the iron trade, and the production of those numerous hardwares for which Birmingham, Wolverhampton, and Sheffield are celebrated. But in the present day we use coal in a much more extensive way than formerly, in the coal blast furnace, in making iron. Another use of coal is in the salt trade, which is confined to a limited district, where the salt rock occurs in Cheshire; but that small district supplies the greater part of the world with salt. Salt was originally derived from sea water, through evaporation, by the sun's rays; instead of the heat of the sun we now use heat from coal, which is employed for boiling the salt pans. Without this cheap fuel, salt could not be produced at its present low cost, so that we are able to send salt to India, Australia, and South America, and almost every part of the world. We use coal again in the chemical manufactures of this neighbourhood. It is almost impossible to carry on any chemical operation without an abundant supply of heat, for boiling, melting, evaporating, dissolving, &c. The chief chemical manufactures are situated between Manchester and Liverpool and on the Tyne, the banks of which river are covered with them, as is evident from the fumes and the great heaps of refuse. But far more important is the iron manufacture, or the smelting of iron with coal. This mode has arisen within the last 100 years. It was not until the middle of the last century that men succeeded in making iron by the use of coal; previously it had been done by charcoal. To such an extent has this trade grown that during the last year 28 million tons of coal were used in smelting and puddling iron, that is making it into wrought iron. In all these trades coal produces heat, which is used directly.

The next use is where we turn the heat into force, as in the steam-engine. I need not in Manchester remind you how much the steam-engine does for us. It is used to do the greater part of

our work, and such is its force that the people of England are said to perform as much work by the aid of the steam-engine, as all the people in the world could effect by hand labour. I will enumerate a few of the uses of the steam-engine. First of all the engine pumps for us, that is to say, it gives us the power of raising water. You may not at first appreciate the full importance of that use, but the engine was invented for the sole purpose of pumping the water from mines, and without the pumping-engine we could never have had our mines to anything like their present depth. The iron trade, again, is impossible on a large scale without the engine; of course iron was made before the engine was invented, but not to the same extent. The utmost difficulty was felt a century ago in commanding blast power sufficient for iron works, and it was only by the engine that the power could be obtained which is necessary for producing large iron plates in the rolling mill. It would be utterly impossible to obtain this power by means of wind mills. From 20 to 50 wind mills would be required to produce the power often needed in a mill, and during one-half of the year there might be no wind at all, and the works would come to a stop. Again, the engine is necessary for all our machinery in Manchester. Steam-boats depend entirely on coal, for not only are their hulls and engines made of iron, but they are propelled by coal. I do not think that sailing vessels will be used much longer for passenger traffic and the conveyance of the more valuable class of goods. There will be as little travelling by sailing vessels as there is now by canal boats. If any of you remember the Liverpool harbour and docks 20 years ago, and know what they are now, you will realize how important a part coal plays in our steam navigation. Again, I need not remind you that our inland conveyance is carried on by coal. The locomotive is made by the use of coal, and it burns coal; the railroad is also made by the use of coal for it is an iron road; and although our railways do a great deal for us, I think they will yet do much more. I do not think we have reached the limit of railway construction even in this country, and as to the rest of the world, with the exception of a few countries, they have yet to make their railways. Probably you think that I have mentioned enough uses of coal, but you must not forget that this room is lighted with coal, and that all our best means of illumination are now derived from coal. For nearly 50 years we have had gas illumination, and it has been gradually extending until now every small town in the country is lighted with gas. But during the last twenty years we have commenced the production of petroleum or paraffin oil, that

now fill our lamps. I think you can get a good lamp for sixpence, and a better light than by any tallow dip for about a farthing per night. Candles used to be made of wax, spermaceti, and other expensive materials; as fine looking candles, and much cheaper ones are made from parafin, which is derived from coal. Nor can we see any end to the uses to which the oil derived from coal may be applied. The thicker oils are used as lubricants, taking the place of palm and other oils. We have used tar for a long time as a kind of paint to preserve wood, but it is only of late years that it has been found to yield a multitude of valuable things, such as colours and scents. The beautiful mauve and magenta colours are derived from coal-tar, as well as the pine apple and other flavours that are used in the manufacture of sweetmeats. We used to think that all the wealth came from India; it comes rather from the "black diamond," as coal has been appropriately named. The coal mines are our Indies. Dr. Roscoe told you the other night that the diamond was nothing but carbon. A diamond hardly larger than your finger end would be worth thousands of pounds, but I think that, according to a just estimate of utility, a ton of coal is far more valuable. Yet you can in some places get a ton of coal at the pit's mouth for five shillings.

Now, considering all these things that coal is capable of producing, we cannot be surprised to find that the coal fields are the chief seats of our industry. I can give a very simple reason for that, namely, that if you carry coal far its price is very much enhanced. Coal at the pit's mouth is perhaps the cheapest thing we use, but its transit to any distance doubles its price. Iron costs £8 a ton; copper, lead, and other metals nearly £100 a ton, yet coal, which is capable of producing all these things costs but 5s. a ton. Although we have developed ways of carrying things cheaply, you cannot carry coals to London without about doubling its price. The best coal, which will be 9s. or 10s. at the pit's mouth, will cost about 20s. in London. In Brighton Dr. Roscoe informs me that coal is 32s. a ton; it is obvious, therefore, that no business can be profitably carried on in Brighton which requires a great consumption of coal. A large number of iron ship-builders in London (15,000 it is said) are out of work. Various reasons have been assigned for this, but I believe the real cause is the high price of coal and iron in London, owing to the cost of carriage. Iron cannot be carried to London without increasing its price about 15s. per ton. The quotations of iron in the London market are always higher than in the Staffordshire market and in the other iron and coal fields. Coal is also dearer

in London, consequently shipbuilders cannot compete with builders on the Mersey and the Clyde. I could never quite understand why the masters established iron ship-building in London, where the articles used are so much dearer; and it is not surprising that several of them have failed. The unfortunate result of this misplaced trade is, that when bad times come, and the demand for iron ships falls off, thousands of workpeople are idle and suffering. To show you how the trades arise upon our coal fields and stick to them, I will show you a plan of the English coal fields. [Professor Jevons exhibited on the illuminated screen a series of maps showing the coal fields and the grouping around them of the great trades of England.] There was no part, it appeared, where population was so concentrated as about Manchester. The South Wales coal fields were said to be inexhaustible. In Staffordshire the coal was 30ft. thick and near the surface. The fields in Yorkshire, Shropshire, Durham, Cumberland, and Scotland, were pointed out. There was a small field of coal in the Forest of Dean, a tract of country which was formerly very celebrated. An immense trade had sprung up in South Wales. The Newcastle field was the oldest. For five centuries Newcastle had supplied London with coal through the coasting trade. From the Whitehaven field Ireland was supplied. The Scotch fields were in Ayrshire, Fife, and the Lothians.

The Professor next pointed out the scarcity of manufacturing towns in the agricultural districts, such as Lincoln and Bucks. In the agricultural counties there were handicrafts carried on, such as straw platting, making boots, gloves, lace, &c. These trades were unknown in the mining and iron districts, where they had more profitable trades. He mentioned instances to show how trades shifted their locality through the discovery of coal. The woollen trade of England, he said, was for many centuries its staple trade. The Lord Chancellor sits upon a woolsack, as an emblem of England's power. The wool trade was formerly most prosperous in Norfolk, but it had almost disappeared from that county, and was transferred to Yorkshire, because the weaving, &c., was now done by steam power, for which a new and cheap supply of coal was necessary. A more surprising instance was the iron trade. Formerly the iron used in England was made by means of charcoal, and the chief seat of the trade was Sussex. The charcoal was got from the woods, taken to a small forge, and power was got from a waterwheel. About 200,000 tons were thus yearly produced in this country a century ago, not more than is now turned out of one iron works. The iron trade has now

removed to Staffordshire, South Wales, Newcastle, and Scotland, and there is not a ton of iron now made in Sussex, or anywhere near it.

It is difficult to express what a contrast Lancashire now presents to its former condition. About the year 1400, four centuries and a half ago, it was looked upon as a kind of morass or waste, and the people were supposed to be so uncivilized that travellers did not like to venture into it. Some ancient documents recently discovered, show it to have been about the poorest county in England.* One of the most reliable early English writers was Camden. In his "Britannia," a celebrated book, he speaks of Lancashire as "that country lying beyond the mountains towards the western ocean." He spoke of the people of Lancashire as if they were but half civilized. He says, "first of all, the people whom I approach with a kind of dread. However, that I may not seem wanting, I will run the risk of the attempt, hoping that the divine assistance which has favoured me hitherto will not fail me now." That is the way in which he regarded our forefathers—for I have the pleasure of being a Lancashire man.

An enlarged map showing the localization of the trades was then shown. Almost every trade was found around Manchester, excepting the great iron trade. He did not know why the metal trades were not more numerous on the Lancashire coal field—but perhaps it was because we had so many other things to do. These trades were, however, springing up, and one of the finest steel works in the country, was that lately built at Gorton. He had hoped to have another map showing the railways, but the snow had prevented it being photographed. This map would have displayed the remarkable fact that the railways were most ramified and numerous close upon the coal fields. In the agricultural districts the railways were fifteen to twenty-five miles apart. The lines that paid best were those connected with the coal fields. Some of the earliest railways, such as the Great Western and the Great Eastern, which ran through agricultural counties, were now the most unfortunate, although at one time great hopes were entertained of their success. On the other hand the railways that ran through coal fields, or were connected with them, especially the London and North-Western, appeared to have the power of developing an endless amount of traffic. This connection of railways and the coal trade, the Professor added, is more intimate than you think. The fact is we owe the railway to coal. Railways

* See Professor Roger's History of Agriculture and Prices in England.

were invented two centuries and more ago for the purpose of carrying coal and for no other purpose, and for nearly two centuries they were used only for carrying coal and a few other minerals. Again, it is by the use of the locomotive, another product of coal, that we have been able to spread railways. And what I want to point out is that the railway system is still necessary for the coal trade, for we could not carry the weight of coal we require by any other means. Twelve of the great railway companies last year carried 50,000,000 tons of coal, the remainder was carried by the other companies, and by canal and sea. The enormous amount of coal we raise depends greatly on the railways for its conveyance to the several towns and villages of the country, and it is only by extending our railways still further that we can develop the coal trade in a way that the coal owners desire. There are at present several schemes afloat for extending our coal railways: one line is to run all the way from Newcastle to London, purposely to carry coal; another is to run right through the Lancashire district, in order to carry coal to Liverpool and to ship it there, as well as to supply the steamers. Another line is designed to carry coal from South Wales to London. Now it is plainly by the use of railways that we develop the coal trade, and it is the coal trade that favours the extension of the railway system; they work one into the other. I will point out another proof of the result of the use of coal depending upon the density of population.

On an average of the whole kingdom there are 344 persons to a square mile. In Lancashire we have 1,280, that is nearly four times as many as in the rest of the kingdom. Staffordshire has 652, the West Riding 564 persons to the square mile. Now contrast that with some of the agricultural counties:—Bucks 230, Hereford 147, Dorset 192, Lincoln 148.

The most striking proof perhaps of what coal is doing for us is shown in the progress of population. All the coal producing counties are increasing very rapidly. Lancashire in the ten years from 1851 to 1861 increased in population 20 per cent, Staffordshire 23 per cent., West Riding 14 per cent, Durham 30 per cent. Glamorganshire 37 per cent. Now of these counties Durham and Glamorganshire are the two counties where the coal trade has been developed most rapidly. Compare those numbers with the following for the agricultural counties:—Bucks 3 per cent, Hereford 7, Dorset 2, Lincoln 1, Somerset no increase at all; but that is a great deal better than a falling off, which we find in a good many counties. Suffolk diminished 2 per cent in population, Wiltshire 2, Cambridge 5 per cent.

I might go on to point out the changes in towns. It is curious that the larger towns are the more rapidly they increase proportionately to their size. I will read a sentence from the census report:—"The towns where silk and woollen goods and gloves are made increased slowly; the towns famous for cottons, for stockings, shoes, and straw plait increased more rapidly. The increase of population was most rapid in the seaport towns, and in the mining districts, where hardware is made, in that direction the tide of natural industry has recently flowed."

I might show you in another way what coal does for our manufacturers, by accounts of the quantities of goods produced, by showing in short upon what we live. It is obvious that we live to a certain extent upon the wheat, barley, oats, potatoes, cattle, and garden produce of our fields, gardens, and dairies. We also spin and weave the wool of our own sheep, and the flax grown in Ireland. But it is obvious that these products are not capable of much increase. On the other hand we use every year a great quantity of foreign produce, not only wheat but things that do not grow in England. Thus we get sugar from the West Indies, tea and silk from China, rice and spices from the East, and cotton from almost all parts of the world. How do we get these things? Of course we have to pay for them. For every £100 worth of material brought into the country we must send out £100 worth in return. To India we send a great deal of gold that we get from Australia, and we send silver got from South America. But how do we get the gold and silver? We must pay for them. We get them by means of our coal produce. We work all these materials up into things which other nations desire to buy, and it is only by constantly shipping more and more goods that we get more and more additions of material and food. The consequence is we must go on using more and more coal in our manufactures.

I will now draw your attention to the quantity of coal we use, and the value of it.

Perhaps you might say that it is not our coal alone that is so valuable, but our copper, iron, and lead mines. But these are unimportant in comparison with coal. I can tell you exactly what these things are worth. Mr. Hunt, of the Mining Record Office, in London, states that in 1865, the value of the ores raised was:—iron, copper, lead, &c., £7,821,000; coal £24,537,000; so that the value of coal is three times as much as the other minerals. You may see this in another way. We not only use our own copper, lead, iron, and other ores, but we import largely from other countries. The fact is that the Cornish copper mines are beginning

to fail, and we can get metals cheaper elsewhere. Many years ago there prevailed a notion that we were using a great deal of coal, but there were only wild guesses as to the quantity, until 1854, when the first return was made at 64,600,000 tons. Since then we have had accurate accounts of the consumption of coal every year. The following table shows the quantity of coal raised and exported in Great Britain from 1854 to 1865 :— (See Postscript, p. 114.)

COAL TRADE OF GREAT BRITAIN.

Year.		Coal raised.		Coal exported.
1854	....	64,661,000 tons	....	4,309,000 tons
1855	....	64,453,000 ,,	....	4,976,000 ,,
1856	....	66,645,000 ,,	....	5,879,000 ,,
1857	....	65,394,000 ,,	....	[illegible],737,000 ,,
1858	....	65,008,000 ,,	....	6,529,000 ,,
1859	....	71,979,000 ,,	....	7,081,000 ,,
1860	....	83,208,000 ,,	....	7,412,000 ,,
1861	....	85,63[illegible],000 ,,	....	7,222,000 ,,
1862	....	83,638,000 ,,	....	7,694,000 ,,
1863	....	[illegible]8,292,000 ,,	....	7,529,000 ,,
1864	....	92,787,000 ,,	....	8,063,000 ,,
1865	....	98,150,000 ,,	....	8,585,000 ,,

Last year people were rather alarmed to find that the consumption had risen to 98 million tons. It is hard to form a notion of what a million is. At the Crystal Palace they have printed a piece of calico with a million dots, to enable people to see how many a million is, but you cannot take in the number with the eye at all, consequently you cannot conceive what a hundred millions would be. But to give you some notion of what the weight and size of this coal would be, I have drawn here a representation of the Great Pyramid of Egypt, and another picture by the side of it, of the much greater coal pyramid which we consume every year. The Great Pyramid, it is said by Herodotus, was twenty years in building, and it took 100,000 men all that time to raise it. It contains 3,394,307 cubic yards of stone. The coal raised last year would make a Pyramid of 100,000,000 cubic yards, since a cubic yard of coal weighs very nearly a ton. The quantity of coal we raised is therefore thirty times as much as the Great Pyramid, which is considered one of the greatest works ever erected. The largest stone work in England is said to be the Plymouth Breakwater, but the Great Pyramid contains six times as much stone as that; yet our coal raised in one year was thirty times as much as the stone in the pyramid!

The question has been suggested by a number of writers as to whether sooner or later, we shall not get to the bottom of our coal mines. A hundred million tons of coal is an enormous

quantity to consume every year; but it is not this amount that is so alarming as the rate at which the consumption increases year by year. In 1865 we used half as much again as in 1854. Now if we go on in that sort of way—if in 1876 we use half as much again as we do now, and still went on in that way, we should get to amounts that would be alarming to contemplate. Some people say we shall not do so—that we shall economise our coal, use it more carefully, and get more power out of it in the steam engine. The fact is, we are doing that now. Iron is now made by much less coal than it used to be, yet we use more coal than ever. Engines are better now than they were in 1854, but this has not cut down our coal consumption; then what is the likelihood that it will do so in the future? The fact is that coal is a thing of such value to us that we cannot help spending it—there is more temptation than we can resist. It is such a useful substance that we find wealth in it more and more every year. The consequence is there is one trade that always seems brisk. If you read the trade reports in the newspapers, you will see that the Cardiff steam coal trade always seems to be brisk. But, I ask myself, is it really favourable for us to be spending our capital at this rate, and will it always be so?

And again, it is not so much the amount of coal that we use, as that compared with the coal produce of other countries which is astonishing. It is obvious that our enormous power of coal partly explains our extraordinary position in the world. You will appreciate what I mean when I compare the total produce of coal in Britain and in the world. We used 98 millions; now the known coal produce of the whole world is said to be 164 millions, so that we used 60 per cent of the coal used in the whole world, although we are only 30 millions of people out of about 1,220 millions. All the Anglo-Saxon nations together use 116 millions, or 70 per cent—seven parts out of ten are used by one race. This may explain, in some degree, the advance of this race in material power and possessions. But then we ought to look at the comparative quantity of coal in different parts of the world. Professor Jevons referred to a map showing the proportion of the coal in various countries. Russia was said to have a large quantity of coal, but scarcely any of it was worked. Australia has a certain supply. New Zealand has a small deposit. The maker of this map has indeed inserted a large black tract, or coalfield, in the interior of Australia. Now, if he is correct, and there are really those extensive coalfields, Australia will probably become the first country in the world. But I am very much afraid it is a

mistake. But when you come to North America we have the most solid reality as to the extent of coal. In the interior there are great expanses of coal of the most perfect quality, and in circumstances most suitable for working, such as the Pennsylvanian and Mississippi fields. The better way will be to compare the relative extent of coal produced in different countries:—Great Britain, 98 million tons; Zollverein, 20; United States, 16½ (rapidly increasing); France, 10; Belgium, 10 (also rapidly increasing); Australia, 4½; Russia, 1½; Spain, 300,000; New South Wales, 250,000; Ireland, 123,000. The last quantity is as much as one respectable colliery in England would turn out. It is said that there is a large area of coal in Ireland, but it certainly is not worth much. Among all the reasons given for Irish misfortune, this absence of coal goes a considerable way.

Now let us compare these products of coal with the quantities believed to exist in different countries. I have represented the extent of the English coal measures by a black square indicating 5,400 square miles; Prussia contains 1,370, much less than England; so with France, 984. The United States contain the largest area of coal in any country—viz., 196,000 square miles. They have the means of developing the coal trade almost indefinitely.

The only thing that remains to be said is as to what we ought to do under the circumstances. The fact is that if other nations go on increasing their yield of coal—especially if America develops her resources, as she must do—then we cannot hold such a prominent position as we do now. I do not say that we cannot always be pretty well off, but we cannot take the lead in the markets of the world, and have the largest shipping and coal trades, and the largest manufactories, because not only shall we find it difficult to get coal for ourselves, but they will be getting a great deal more, and coal will be much more valuable 50 or 100 years hence, because it will be more and more a source of power. Some people think that we ought to begin cutting down our produce of coal, and that we ought to prohibit the exportation to France and other countries. But that is a very narrow-minded view of the question. I do not know that we have a right to keep things to ourselves in that manner. I think it is the duty of every country to use its wealth to the best purpose, and to communicate it in the way of free trade. We do not give them our coal for nothing—we get something for it; and it would be in every way a most short-sighted policy to violate those admirable doctrines of free trade which Manchester has done so much to establish. But

if by increasing our trade we are diminishing our wealth for the future, then we ought to be thinking about that. It strikes me that the best way to prepare for future time is by taking every advantage of the present. I do not think that our descendants will blame us if we take proper precautions to use our coal economically, and to get the best possible return for it—that is to say, the most force and the most wealth, and not to burn it needlessly upon waste heaps, as is sometimes done. And, secondly, when we get this wealth from our coal, we must take care to turn it to the best account. We must use our wealth as it ought to be used. If we use it in mere luxury and mismanagement, such as in our dockyards, we shall be justly blamed; but if we use it in improving the condition of every one, so far as it can be improved—if we use it in providing education, in improving the dwellings; and if we could by any possibility use it so as to do away with pauperism, and to provide libraries and institutions, or anything that will increase the power and improve the character of our people, then I think we shall never be blamed for using our coal too fast. This is the way in which we shall best provide for any future difficulties under which our country may labour.

A vote of thanks to the lecturer, moved by one of the audience, and carried with applause, concluded the proceedings.

POSTSCRIPT.—Several years having elapsed since the delivery of the above lecture, the following additional figures can be given to show the subsequent progress of the coal trade of the United Kingdom.

Year.	Coal raised.	Coal exported.
1866	101,630,000 tons	9,367,000 tons
1867	104,500,000 ,,	10,565,000 ,,
1868	103,141,000 ,,	10,967,000 ,,
1869	107,427,900 ,,	10,744,000 ,,

FOUR LECTURES

ON

ELEMENTARY PHYSIOLOGY.

LECTURE I.

FOOD AND DIGESTION.

PHYSIOLOGY concerned with the workings of the animal body. The body is in a state of constant renovation and decay. The body compared to a steam engine at work.—How is the body kept warm? How is it repaired?—Food. From what elements derived—Oxygen, Hydrogen, Nitrogen, and Carbon—Experiments showing some of the properties of these gases. Plants prepare food. Plants absorb carbonic acid, water, and ammonia from the air—animals eat plants. The principles of the animal body are found in plants—albumen in cabbage—fibre in wheat—casine in peas.—Flesh-making food—Heat-giving food—fat starch—mineral food—diet of the Esquimaux. In the process of digestion food is rendered soluble and pulverised. The mouth—its structure—changes which the food undergoes in the mouth. Insalivation—swallowing. The stomach—structure and situation of the stomach—gastric digestion—gastric juice—acid in the stomach—endosmosis—exosmosis. The pylorus the commencement of the small intestines. The bile and pancreatic juice—fat converted into an emulsion by the bile.

THE subject, my friends, upon which I am going to speak to you this evening, and on several other occasions, is a very interesting and a very important subject—it has to do with the workings of our own bodies. I dare say there are many men in this room who are skilful mechanics, who know a good deal about the working of intricate machines. Many of you, I doubt not, thoroughly understand the mechanism of a watch; others again are acquainted

with the steam engine; others can explain how the microscope and telescope are put together; but I engage to say that very few of you know anything about what goes on in your own bodies. Surely these machines are as important to us as any of those I have mentioned. Now, it is with the workings of these machines that physiology has to do. Physiology is a long word, and in the course of my lecture I will try, as far as I possibly can, to avoid all long words.

You know that our bodies are made up of a number of different organs and tissues. In the first place there is the heart, the central pump in the middle of the body, which distributes the blood through its vessels. Then, again, there are the lungs which purify that blood. Then, again, there are the stomach and bowels, which prepare the food, and gradually turn it into blood. Then, again, there are the brain and the nervous system, which regulate the whole working of the frame. Now, it is with all these that physiology has to do; it is concerned with their functions. The word function means the same thing as duty. The different organs and tissues have all distinct and separate duties or functions; and the science which deals with them is called physiology.

Our bodies have been compared with the steam engine, and there is a certain similarity in the manner in which the one and the other fulfil the work assigned them. Look closely at the steam engine. What takes place there? You put fuel into the furnace, the water in the boiler is heated, and expands into steam; then the piston works up and down, this moves the wheels, joints, and levers, and so the whole engine is set going by the fuel or coal which is put into the furnace. Now, just the same thing happens in our bodies. We take food, that food passes into the stomach; by reason of that food we are kept warm, muscular force is developed, and the levers and joints within us are set working, as we see in the steam engine. There is, however, an important difference between the two. You know that the burning of the coal in the furnace has a tendency to wear out the sides of the boilers; and the passage of food through the stomach also has a tendency to wear out its coats. How is this wear and tear renewed? It is renewed by the food, for we not only take food to warm us, but we also take food for the building up and repairing of the body. It is not so with the steam engine. When the iron boiler is worn out, we cannot throw in masses of iron to be converted into a new boiler, or to repair the old one; but we are forced to stop the working of the engine

and to put in new plates. You see, therefore, that our bodies far surpass the steam engine, in the perfection of their mechanism, inasmuch as they are *self-repairing*.

Having told you that our bodies are both repaired and kept warm by food, let me say a few words now in regard to that food; of what it is composed. If we separate food by chemistry into its constituent atoms, we come to certain elements beyond which it cannot be divided. What are those elements? They are principally four, oxygen, nitrogen, hydrogen, and carbon. These four elements enter largely into the composition of food. Now of these elements three (hydrogen, nitrogen, and oxygen) are gases. Does it not appear to you a marvellous thing that elements, which when separate are mere gases diffused through air and water, should, when combined together chemically, form solid articles of food? In addition to the three gases, there is also carbon. Now what is carbon? You have all seen it in charcoal; another form of carbon is the diamond. I will now try to show you a few of the properties of these elements. And first as regards oxygen. Oxygen is the gas of which there is about one-fifth always present in the air. There is about that proportion in this room at the present time, and the other four-fifths are composed of nitrogen. In the air these two gases are not chemically combined; they are merely mixed together, diffused one through the other. Now it is a curious fact that when they are not actually combined, the nitrogen appears altogether inert! it seems merely to render the oxygen less active; in fact it has a diluting effect, such as when water is mixed with brandy. Dr. Morgan then burnt a piece of phosphorus in a jar of oxygen, which emitted an intensely brilliant light. This illustration showed the power of oxygen to support combustion. He next explained that hydrogen was itself inflammable, for the moment a lighted paper was inserted into the jar it became ignited, because of the oxygen of the air combining with it. The result of the combination being the production of a small quantity of water—a combination in fact of oxygen and hydrogen. Another experiment showed still more strikingly the close affinity of these two gases. It was the explosion of a bladder filled with oxygen, the report being as loud as a cannon.

I am not showing you these experiments, continued Dr. Morgan, merely to make a blaze or cause an explosion, but to impress upon your minds some of the properties of these elements, and that we are concerned with them because they are the principal elements of food. Another element of food is nitrogen, with which this jar is filled, and you perceive that it has the power of extinguishing flame: the moment I introduce this candle it goes

out. The last of the elements I shall bring before you is carbon; look at this piece of charcoal; that does not look a very tempting ingredient of food; nevertheless this carbon, when it is in combination with these gases, assists in forming some of the most savoury and delicious articles of food. You must allow that this is strange—that these mere gases and this black charcoal, with perhaps a little sulphur, can by any process be elaborated into food. Now let us consider how this takes place. By what agency is it done? It is done by plants. Our stomachs could not get food directly out of these gases and this charcoal; plants can; and let me here remark, there is one obvious advantage in these gases being diffused throughout the world, for so they are everywhere present, and brought into contact with the plants. Plants cannot go about and seek their food like animals. therefore it is necessary that the food should come to them, and it comes to them after this manner. The elements have a natural tendency to combine, so oxygen combines with carbon and forms carbonic acid, nitrogen combines with hydrogen and forms ammonia, and oxygen and hydrogen together form water. How this is effected we know; not but we may suppose that one little bit of carbon is taken hold of by two little atoms of oxygen, each impressing on the other some change wherefrom results carbonic acid—the same sort of process leads to the formation of water and ammonia. Ammonia is the pungent gas which, when you smell it, stings your nostrils and brings tears into your eyes—you can easily make ammonia by putting some horns, hoofs, or nails into an iron tube, and then heating the tube, when ammonia will be given off. Ammonia is present in the air, sometimes to a considerable extent, especially after thunder storms. Ammonia is also present in large quantities in the soil, in fact the richness and value of manure depends in no little degree on its ammonia.

Carbonic acid is also present in the air. There is a considerable quantity in this room, and so there is of water in the form of vapour. Now upon water, carbonic acid, and ammonia plants are able to support themselves. What do they do? Why the moment the carbonic acid comes into contact with their leaves they take hold of the carbon, the solid part, and store it up, setting the oxygen free. In the same way they make use of the ammonia and the water, which, after entering upon new combinations, are stored up within them. In this way plants prepare food out of the soil and the air.

What do animals do? You know that animals feed on plants. Now it seems natural that when we eat the flesh of animals it should be turned into human flesh; but it seems extraordinary

that wheat, and flour, and oatmeal, and things of that kind, should be turned into muscle, and that we should be able to get food out of those substances. If that surprises you, you will cease to be surprised when I tell you that there are the same principles of food in plants that exist in animals. In animals we find, for example, a constituent of food called "albumen." You know what white of egg is; it is that sticky substance which surrounds the yolk of the egg, which becomes white and hard when the egg is boiled. Albumen is also present in meat to a considerable extent, and it is present in the blood. In every thousand parts of blood there are seventy parts of albumen, and this albumen is actually converted into the flesh of which our bodies are made; now this albumen is also present in vegetables, as wheat and oats. Then again in meat you have another principle, called fibrine. You can produce this fibrine for yourselves. If you take blood and beat it with a switch, you will find a number of gluey particles sticking to the switch; these gluey particles are made up of fibrine. You may have noticed that when blood is allowed to stand it gets solid after a time, or clotty. Its coagulating is due to the presence of this fibrine. Fibrine is also present in vegetables.

Another principle of food is gluten, which is very like the fibrine contained in flesh. If you take a little flour and wash it in a bag you will have a sticky mass remaining—that sticky mass is composed of gluten. Gluten exists abundantly in vegetables—casine is another of these nitrogenous substances. You have seen it in curd, the coagulable part of milk—it is an important ingredient of cheese—this casine also is found in peas, beans, and nuts. Now you can readily understand that if such principles as these exist in vegetables as well as in animals, it is not surprising that our bodies should be able to convert them into flesh.

Food may be divided into three great classes. In the first class you have that food which goes chiefly at all events to warm the body. In the second class you have the food that goes to build up the tissues of the body. And, thirdly, you have what may be called mineral food. Now the food that warms us is principally made up of three of these elements, hydrogen, carbon, and oxygen. For example, in oils, starch, sugar, and all that kind of food, those three elements are present; food of this kind is the most heating. Let me now say a word of the manner in which food warms our bodies. We are warmed very much in the same way as a lighted candle or fire warms a room.

Professor Rocoe in one of his lectures explained the chemistry of a candle. What takes place when a candle is lighted? Simply

this. In the tallow of the candle you have the two elements, carbon and hydrogen. When the candle is lighted the oxygen of the air unites with those two elements, just as I showed you in my experiment, but not with so much noise, and water is formed, and carbonic acid—in fact the whole candle is completely changed into the liquid water, and the gas carbonic acid. When many candles are burnt in a room you would perhaps expect that an immense quantity of grease would be spread over the walls. No such thing, because the grease is completely changed; after burning it is no longer grease, but is turned into the vapour of water, and the gas carbonic acid both diffused through the air. Exactly the same thing takes place inside our bodies. All through the animal frame, in the blood, and the different tissues, there is a great quantity of this carbon present, and there is also a great quantity of hydrogen present, much of which has entered the system as fatty food. Oxygen is brought into contact with that carbon and that hydrogen through the lungs, being diffused through the blood, and whenever oxygen comes into contact with hydrogen and carbon, carbonic acid is formed and also water, and wherever that union takes place, a certain amount of heat is given off. The heat is gradually given off through all hours of the day and night, in consequence of these changes taking place in this manner. In this way every day in the bodies of each one of us, from 7 to 12 ounces of carbon are burnt. If we take but little exercise, then only 7 ounces will be burnt, but if we work hard perhaps as much as 12. Now the food which is most rich in this carbon and hydrogen is fatty food, such as oil, tallow, suet; after fatty food the next most heating food is starchy food, such as flour, tapioca, sago, and sugar; they all contain much carbon and hydrogen—they all take an active part in keeping us warm. Now although this fatty and starchy food contains much hydrogen and carbon, together with a certain quantity of oxygen, the element of nitrogen is altogether absent; but there is another class of food in which nitrogen is present, and the properties of that food seem entirely changed by the presence of the nitrogen. I told you that in the air where nitrogen is merely mixed with oxygen, not chemically combined, the nitrogen seems well nigh inert, like water when used to dilute brandy; when, however, it is present in food it entirely alters the character of that food; it is then not so much used for heating purposes as for the building up and repair of the body. Now remember that you have these two great classes of food, the "flesh formers" and the "body warmers." Do not, however, be led away by divisions of this kind, but bear

in mind that fatty and starchy food, though *chiefly* employed in warming us has some share in the forming of our structures, while at the same time the food containing nitrogen materially assists in keeping us warm. These remarks on food will enable you to understand how it is that in very cold climates people are able to take very large quantities of fatty food. Sir John Ross states that an Esquimaux will eat daily 20lbs of flesh and oil, while a Yakut thinks little of a couple of quarts of train oil, and a dozen tallow candles. In addition to these two classes of food there is a third class which may be called mineral food. It may appear strange to many of you, but it is nevertheless true, that minerals such as iron, lime, soda, potash, sulphur, and many others, actually enter into the formation of our bodies. Chemistry enables us to separate these minerals from the tissues with which they are united. I have been told that on one occasion a Frenchman, deeply affected by the loss of a relative, ordered the remains to be burnt, and after separating the iron from the rest of the ashes, had it moulded into a mourning ring; the ingenious foreigner, not content with wearing mourning for his friend, actually made mourning out of him. So much with regard to food.

Let me now say a few words to you in regard to the digestion of food. What is digestion? In the process of digestion those particles which go to nourish the body, and which are really useful to the building up and warming of the tissues, are separated from those parts which are useless, and which are thrown out of the body. For example, different kinds of food, such as starch and tapioca, are surrounded by a little envelope or covering, which prevents them from being dissolved. Muscular fibre is also thus covered. The great object of digestion is to separate those parts that can be dissolved from the outer covering which cannot be dissolved, and which cannot go to the repair of tissue. I will now explain what takes place when food is taken into the mouth. Here we have a mouth. [There were numerous drawings of parts of the human body on the wall, as well as full length figures.] What is the structure of the mouth? The mouth is a hollow box with a moveable floor formed by the tongue and lower jaw. In the mouth are thirty-two teeth, sixteen in each row; the two rows are divided in the middle of the mouth into two equal sets of teeth, two incisors or cutting teeth in front; then the eye tooth, next those with two points called bicuspids, and farther back three large teeth, the grinders. The moment food enters the mouth it is moved about by the tongue, while the teeth are employed in crushing and grinding it into very small pieces. This process is

called chewing or mastication. While this chewing is going on, the food is moistened by the saliva, which is chiefly poured out by three little glands. One of these glands is situated under the ear, the other two under the tongue. These glands look something like the inside of a walnut when the shell is removed, and if you minutely examine their structure you will find it bears a certain resemblance to a bunch of grapes; but instead of the stalk which supports the grape-like protuberances being solid, as in the vine, it is a hollow tube. The little vesicles of the gland are also hollow. It is from the interior of these glands that the watery secretion called the saliva is poured out. You know that sometimes these glands are busily at work even before you actually taste food. This occurs when the mouth "waters." You have all felt this sensation, when, perhaps, a savoury dish has passed you in the street, or you have looked with longing eyes through the windows of a pastry-cook's shop.

Now the saliva is not simply poured out, but is actually formed and prepared by these glands. How is this done? Why the extremities of the glands are fitted with a countless number of "little cells," like very "minute bladders." These cells derive their nourishment from the blood, and are formed rapidly, as soap suds are formed when you blow into soap and water—as each little cell reaches its full size it bursts and pours out its contents—and the fluid which is poured out is the saliva. This goes on continually, these glands pouring out in the course of a single day as much as three or four pints of saliva. This saliva is mixed with the food. It does not mix with it merely for the sake of softening down the food, but it induces in it a particular change, especially in the starch of the food. Bread contains, as I have said, a large quantity of starch. After you have turned the bread over in the mouth a few times, it seems to acquire a different taste, and becomes sweeter; the reason being that part of the starch in the bread is changed into sugar by the action of the saliva, and in consequence of that change the starch is rendered soluble. Sugar is soluble; starch is not. Starch is contained in little envelopes, sugar is not. Consequently by the bread being turned over in the mouth it is rendered soluble, and can be taken up into the tissues of the body. This should impress upon you the importance of *thoroughly chewing your food.* If people bolt their food, this chemical change cannot take place, and consequently the starchy portions of the food do not nourish to the same extent.

Let me next explain to you the manner in which food is swallowed. I told you that the first process which the food

undergoes in the mouth is that of chewing; then co es the chemical change which converts the starch into sugar; it is then swallowed. What takes place in swallowing? Every one knows or can readily discover for himself, that in swallowing the tongue is carried up to the roof of the mouth. A sort of hollow curve is then formed in the tongue, the food is placed there, and pressed against the hard palate, at the end of which there is a sort of curtain of flesh, called the soft palate. If you look into your mouth, you will see the prolongation or projecting point of this soft palate which is called the uvula. The moment the food gets to the back of the mouth, the soft palate is pushed upwards, so as to shut off the cavity into the nose. If the soft palate is destroyed, as it is in some cases, then a part of the food comes back through the nose. The tongue then closes the aperture which passes down to the lungs—by covering it with a trap-door called the epiglottis—while the food is grasped by the muscles which surround the gullet or swallow, and is carried down into the stomach. The first part of swallowing is voluntary; that is, you have up to a certain point command over it; but you cannot stop it after the food reaches a certain point, as you may have noticed when you have unintentionally swallowed a plum stone. When the food leaves the mouth the muscles of the gullet press upon it from above downwards, something in the same way as you would run a ring along a tube. [Dr. Morgan then showed drawings of the stomach and glands of the mouth.] After passing down the gullet the *food* reaches the stomach. Now what is the structure of the stomach? It is a muscular bag surrounded by a sort of strong fibrous tissue, like a covering of brown holland pasted round an india-rubber bag. Inside you have a number of ribbons of flesh or muscle. I must remind you that one of the properties of muscle is its power of contracting; when muscles contract their fibres grow shorter, and the parts they surround narrower. Now the moment the food enters the stomach the muscles of the stomach begin to contract, and the whole organ takes on a sort of churning motion, first from left to right, and then from right to left. Were you to view casually the stomach of a man, or a pig's stomach, which is singularly like a man's (not a very flattering fact), you could form but a faint idea of its wonderful mechanism. If, however, you are skilful in the use of the microscope, and examine the inner coat with a high magnifying glass, you will find it covered by a number of little depressions—portions of the lining of the stomach which sink lower than the remaining parts—opening into each of these depressions you will find numerous little tubes. The moment

food enters the stomach these little tubes give out, after preparing it from the blood, a very peculiar juice, called the gastric juice or juice of the stomach. Now this gastric juice exercises a particular influence upon certain ingredients of the food, and the part on which it chiefly acts is the flesh-forming portion—that in which I have told you the element nitrogen is present. The gastric juice contains a ferment, called pepsine, something of the nature of yeast—an acid is also present in the juice, probably muriatic acid, or spirit of salt. When meat and sundry other articles of food are taken, the gastric juice dissolves out the flesh which is packed away in little sheathes or envelopes, and it is then softened down into a soluble pulp. A great part of this soluble pulp enters the vessels of the stomach and is directly conveyed to the blood. Let me now try to explain the way in which this takes place. If you look at the syllabus of the lecture you will see two long words, "endosmosis" and "exosmosis." To your minds those words may not convey any very clear or definite idea. I will endeavour to make them plain to you. Suppose you put some water into a bladder, and then dip that bladder into another fluid, say salt water, you will find that the water in the bladder passes out to the salt water outside. The reason is, that the water outside is of greater density or weight than the water inside. The same thing takes place in the nourishing of the body. You have fluids of one density outside the tubes and fluids of another density inside the tubes; and, as a consequence of that difference, in density there is a constant interchange of the fluids, which are merely separated by the coats of the vessel. If you will bear this in mind it will assist you very much to understand the manner in which parts of the body are nourished. Endosmosis is the passing of a lighter fluid to the heavier, and exosmosis is the passing of a heavier fluid to the lighter.

There are, as I have said, certain parts of food that do not nourish the body, and therefore they are cast out as waste. There are parts also on which the gastric juice exercises no power, and therefore they also are passed on, in order that they may be acted upon by other organs which are situated lower down in the alimentary canal. You will remember that I told you that a portion of the starchy food is acted upon by the saliva of the mouth, while the nitrogenous food is changed in the stomach. After remaining in the stomach some three or four hours those portions of it which are not absorbed are passed into the bowels through the opening called the pylorus. The bowels, or continuation of the stomach, consists of a long tube, averaging about

four times the length of a man, or some twenty to twenty-five feet in length. This tube is coiled away in the cavity called the abdomen. You have all seen sausages; well, the covering of the sausage is made of the gut or bowel of the pig. So in man there is one continuous tube passing through the whole of the alimentary canal, and the first part of this tube is called the duodenum. Let me tell you what goes on in this duodenum. Into this part two tubes enter, one comes from the liver and brings the bile, and another comes from the pancreas. I will show you those organs. The pancreas is probably better known to you by the name sweetbread. Under the liver is the gall bladder. The two tubes from the pancreas and liver join together and enter this part of the gut. When the food comes out of the stomach it is acid, but in passing along the duodenum it is made alkaline by the mixture of bile, which contains soda, and also by the mixture of the pancreatic juice. [Dr. Morgan performed another experiment to show the difference between an alkali and an acid. When an acid was added to a blue liquid it made it red, and when an alkali, such as soda, was added, it turned the liquid to its original colour.] At this portion of the alimentary canal another change is effected.

When the food comes out of the stomach the fat is still but little changed. Change in the fat commences in the duodenum. The fat is there acted upon by the alkaline bile and pancreatic juice. You know that in soap alkali is mixed with fat and is thus rendered soluble. By an alkali being mingled with the fatty food, the fat is changed into emulsion and rendered soluble, and so made fit to be taken up in the bowels. Thus, in the mouth a portion of the starchy food is changed into sugar. In the stomach the nitrogenous food is acted upon by the gastric juice, and in the bowels the fat itself is so changed as to be rendered soluble. But besides converting the fat into an emulsion, the bile and pancreatic juice assist in rendering soluble those portions of the starchy food which were not changed by the saliva. After the different ingredients of the food are in this manner rendered soluble, what has not been already taken up is passed along the intestinal canal. This is effected in the following manner:—The bowels are surrounded by ribbons of muscles. These muscles contract as the food reaches them almost like a ring; then the next part below this ring contracts after receiving the intestinal contents, which have been pressed down from above, and in this manner a sort of constricted ring traverses the whole course of the tube. As the food is thus passed along, everything that is fit to be taken up is absorbed, and the husks and those parts which are insoluble are carried on and cast out of the body.

Dr. Morgan described, by the aid of diagrams, highly illuminated, other parts of the human body, as well as the internal structure of the dog. In conclusion, he expressed the difficulty he felt in making his language sufficiently clear without the use of scientific terms; but he hoped he had been plain enough to be understood. There was hearty applause at the close of the lecture, and at salient points of its progress.

FOUR LECTURES

ON

ELEMENTARY PHYSIOLOGY.

LECTURE II.

DIGESTION, THE CHYLE, AND THE BLOOD.

REMARKS on the teeth of different species of animals, as showing their adaptation to the food they subsist on.—Peculiarities in the hinge of the jaw.—The teeth and jaws of man.—Man is intended to live on a mixed diet.—Reasons for his not living on a vegetable diet.—Reasons for not living on meat alone. Are the flesh-forming principles of certain vegetables as nutritious as those contained in beef or mutton? Probably not. The experience of railway contractors respecting food.—Head work.—Brief summary of last lecture.—Experiments. The chyle. The villi—the lacteals—mensenteric glands. The receptacle of the chyle.—The blood—composition of the blood. The clot—serum—the red corpuscles—their size—shape—uses—fibrine—properties of fibrine—albumen—fat—remarks on the purification of the blood.

AT the conclusion of my last lecture, my friends, a wish was expressed by some of my hearers that I should say something more respecting the teeth, with a view of showing that the teeth of different animals are especially adapted for their food; and, at the same time, I was informed that some further remarks on the relative amount of nutriment contained in vegetable and animal food, would be acceptable to you. As these subjects are both important and interesting, I propose to touch upon them briefly, before I proceed to speak of the chyle and the blood, which you

will see by the syllabus are to occupy our attention this evening. I have here the teeth of certain flesh-eating (carnivorous) animals as the lion and the hyena; if you examine these teeth you will see that the grinders are depressed on one side so as to have sharp edges, and hence, when the teeth in the lower jaw are brought against the upper teeth, the food is cut to pieces and broken up, something in the way that a pair of scissors act upon the material they are intended to cut. This structure of the teeth is best adapted for separating the fibres of the meat, and thus fitting it for being acted upon by the juice of the stomach. I now show you the tooth of an animal which feeds on vegetables (a herbivorous animal), you will admit that it is large, and you can fancy that it would require a pretty hard wrench on the part of a dentist to extract it; probably a crowbar would be a more suitable instrument than a forceps. It is the tooth of an elephant; you will observe that it is covered by sort of ridges and furrows, the same kind of arrangement that you see on a millstone. The corn or grass is brought between the teeth, and then the lower jaw is rubbed against the upper; you can understand that teeth of this construction are peculiarly well adapted for breaking up the food and reducing it into a pulp. In animals of another species, the insect eaters (insectivorous), the crowns of the grinders are sharpened into points something like the teeth of a file, as you see them in these teeth of the ant-eater. The ant-eater feeds upon ants. He quietly spreads out his tongue in the middle of an ant-hill, the ants walk about on its surface quite at their ease; at length, when the animal thinks the tongue is sufficiently covered with the insects, he draws it in, and crushes them between the file-like processes of his teeth. Such, then, are some of the different forms of teeth found in different species of animals, and as the teeth vary, so likewise do the hinges by which the lower jaws are attached to the bones of the skull. In flesh-eating animals there is a simple transverse hinge, and the jaws merely move up and down in their sockets. That is the way in which this jaw of the hyena which I hold in my hand does its work. It is, in fact, a sort of snapping movement of the jaw. On the other hand, in many of the animals which feed on vegetables, the socket and the portion of the lower jaw which joins it are both nearly flat, and so admit of the side to side movement necessary for chewing the kind of food on which they live. We find some such arrangement in the jaws of animals which chew the cud; here much lateral movement is needed. Then, again, in the class of animals which we know as the gnawers (the rodents), the upper portion of the

lower jaw moves along a groove running from before backwards, like a plane. You will have noticed that squirrels, rats, rabbits, hares, and other animals which belong to this class, in nibbling at their food sometimes advance and then again draw back their lower cutting teeth. Now, the jaw of man differs from that of almost all other animals; but, though it differs from that of each class taken separately, it still partakes more or less of the peculiarities of the several varieties I have spoken of. The hinge here, instead of forming a mere tranverse ridge, is fitted on to its socket obliquely, slanting from before backwards, enabling us to advance one side of our lower jaw while we draw back the other side. In this manner the rotatory movements necessary in chewing our food are much facilitated. But not only does the joint of the jaw in man partake of the varieties observed in many other species of animals, but the teeth likewise are, as it were, intermediate in structure. Owing to this arrangement of the jaw and this formation of the teeth, we can, with the most perfect readiness, either move our jaws from side to side as the vegetable feeders, or with a snapping movement as the flesh-eaters. We can either eat meat or biscuits; and if we do not possess in our teeth those peculiar little processes which are met with in the teeth of the insect-feeders, I have still little doubt that should it ever become fashionable to eat insects, we could readily adapt ourselves to the mastication of this kind of food.

Thus, then, physiology teaches us that man is intended to eat different kinds of food, and what physiology teaches experience endorses. We can live much better upon a variety of various kinds of food than on any one kind. In Ireland, before the potato famine, the poor in many parts of the country subsisted almost entirely on potatoes and buttermilk. Now, if a man is to live on potatoes he will require from 10lbs. to 12lbs. every day; the reason being that potatoes contain so small a proportion of the material which goes to build up the tissues of the body, the flesh-forming ingredients of food. You will see from this table of the composition of food, that whilst in 100 ozs. of potatoes you get twenty-three ozs. of heat-giving food, you get less than two ozs. of flesh-making food. Consequently, when a man is reduced to such a diet, he is compelled to take far more heat-giving food than is absolutely required to keep up the warmth of his body, and he is forced to do this in order to obtain from his food the requisite amount of the flesh forming principles. On the other hand, suppose a man were to live on meat alone, such as beef or mutton, then, in every hundred ounces of meat, he would

get upwards of twenty ounces of flesh-making food and only fourteen of heat-giving food. To support life, therefore, on meat alone he would require to take about six pounds of meat every day, because he could not obtain from a smaller quantity the requisite amount of heat-giving ingredients. This, therefore, would be both a wasteful and expensive diet.

But there are other reasons opposed to such a diet; I told you in my last lecture that the labour of digestion is distributed over several portions of the alimentary canal. The digestion of the starchy food being conducted in the mouth and bowels, and that of the meat in the stomach. Now, if you live on any single article of diet, you are apt to overtask the digestive powers of particular organs. Hence, by living on potatoes you derange the digestive powers of the mouth and bowels; by living on meat those of the stomach. Moreover, you can readily understand that the partaking of a large quantity of some one kind of food, when it would be possible for you to support life as well or better on a much smaller quantity of different articles of food, has a great tendency to clog and hamper the general activity and energy of the system. Thus you could not expect a man to be in good order for running a race who had just been eating some ten or twelve pounds of potatoes. By so doing he would be unnecessarily handicapping himself. Now, while as we have seen, a large quantity of potatoes and a very considerable quantity of meat are required, when taken separately to support life, yet if we have recourse to a mixed diet we can live, and live, too, in thoroughly robust health on about 2lbs. of bread and about ¾lb. of meat; and this mixed diet is in every respect the best adapted for us. I have enjoyed considerable opportunities of seeing both Irishmen and Highlanders who lived very much upon a vegetable diet, the former on their potatoes, the latter on their oatmeal; and although these men while living on such a diet often look the very picture of health, they are still not in condition for any very hard exertion. They are like horses out at grass, which look sleek and fat, but are ill adapted for running in an omnibus or cab. Men fed on this sort of food will work very fairly in a leisurely sort of way, and they will walk for a considerable time at the rate of about three miles an hour; if, however, you press them, and require them to go at the rate of five miles an hour, you will find that they have great difficulties in accomplishing the task.

Let me, again, say one word on that table of food which is hanging up before you. You see there that dried peas are said to contain a larger proportion of flesh-making ingredients than beef or mutton.

I have been asked by one of my hearers whether they are really more nourishing! Now I think this is a question which experience will answer far better than chemistry—and what does experience say? It very decidedly gives the preference to beef or mutton—not that chemistry is wrong in its figures. The flesh-making food is no doubt present in the peas, but our stomachs have less power over it when stored away in the peas than they have over the fibrine and albumen contained in the meat. In the language of physiology the flesh-forming food of meat is to us more assimilable than that of dry peas. What I have told you is entirely borne out by the experience of railway contractors and others, who require hard work to be done in the shortest time. They will tell you that the capacity of their men for labour is absolutely proportioned to the food they eat, more especially the meat. Dr. Lyon Playfair speaks of a contractor who ordered his workmen to be watched during meal time. Those who shirked their food were marked and sent about their business. If they could not eat, neither could they work. This contractor was a shrewd physiologist, but a cruel master. Before leaving the subject of food, let me tell you that head work takes even more out of a man than hand work. Many of you who work with your hands look upon professional men and others who live by their brains as little removed from idlers—"doing nothing but sitting and writing." If you think so let me tell you you are mistaken—every thought which issues from the brain uses up a portion of the brain's tissue; this brain tissue has to be re-made by blood, and the blood can only be re-made by good nourishing food.

Let me now briefly remind you of what I told you in my last lecture. I told you that certain elements are everywhere diffused throughout the world. The chief of these elements are oxygen, hydrogen, nitrogen, and carbon. Each one of them has a certain affinity or attraction for some one of the other three; it has a desire in fact to be united or married to it. When thus united they are changed, and are then no longer two but one. In this manner oxygen becomes linked to hydrogen, and the two are then water. Nitrogen joins hydrogen, and those two become ammonia, and carbon attaches itself to oxygen, and they then constitute carbonic acid. On these three compounds plants live. In entering the plants, however, they are changed, the plants having the power, as it were, of divorcing them from their former alliances and re-uniting them in new ones. From being monogamous (married to one) they become polygamous (married to several). Carbon, in fact, is then wedded both to oxygen and to

hydrogen, and the three may be seen in fat on the one hand, and in starch and sugar on the other. Or, carbon may be united to both oxygen, hydrogen, and nitrogen, and then they appear in the form of albumen, and fibrine, and casine, and gluten—in fact, in the class of food called flesh-forming food. In this manner plants prepare our food. After preparing it they store it away in little packages, in waterproof coverings, in order that it may not be washed away. These coverings or envelopes are well seen in those magnified drawings of the little starch cells which I here show you. Plants intend many of these little packages to serve as food for their buds and seeds—their future young. We, however, make use of it as our food, and thus rob the little ones. In the process of digestion this food is broken down and dissolved, so that it is enabled to pass through the coats of the little vessels which distribute it to all parts of our bodies. Some portions of it are so changed in the mouth, others in the stomach, and others again along the course of the rest of the digestive canal. All these changes, you will remember, I fully explained to you in my last lecture.

[With a view of impressing upon his hearers the chemical changes the food undergoes in the process of digestion, Dr. Morgan performed the following experiments:—He placed some crumbs of bread and a little water into a flask, and then tested for starch by adding iodine. The well-known purple colour showing the presence of starch was very apparent. Some more bread crumbs were then tested for sugar, by the addition of sulphate of copper and a solution of liquor potassæ. The flask was boiled for some time, but there was no trace of sugar. The same tests for sugar were then applied after the bread had been subjected to the action of the saliva, and on again testing, the orange tint indicative of the presence of sugar was plainly visible. Dr. Morgan next showed two more flasks. Into one of these flasks minced meat and water had been placed. The meat was shown to be unchanged, although the water had been added to it several hours before. In another flask water acidified by muriatic acid had been poured upon some small pieces of meat. The gastric juice of the pig, in the form of pepsine, was afterwards added, and the mixture kept at a temperature of about 100 deg., and occasionally shaken. After standing for three or four hours, the meat was dissolved into a soluble looking pulp. Another flask contained some cod liver oil, which had all the appearance of an emulsion, after it was shaken up with some bile and pancreatic juice. By these simple experiments the action of the saliva on starch, of the

pancreatic juice on meat, and of the bile and pancreatic juice on fat were familiarly illustrated.]

In my last lecture I followed the food in its passage from the mouth to the bowels; let us now see what are the changes it undergoes in this latter part of the digesting canal. [At this part of the lecture numerous diagrams suspended on the walls were referred to.] The bowels commence at the pylorus or gate of the stomach. The first ten or twelve inches of the tube which composes them is called the duodenum. Two ducts coming from the liver and pancreas, after uniting, enter the duodenum, and discharge into it the bile and pancreatic juice. You will observe that the tube of the duodenum is in several parts partially obstructed by little flaps of its lining membrane, which project across it; they constitute the transverse processes of the duodenum. They serve a useful purpose in preventing the food from being carried too rapidly through the bowels: while it is passed slowly along, time is allowed for its nutritive particles to be absorbed or sucked up, and then conveyed into the current of the blood. When food reaches the bowels it is called chyle, or digested food. Let me now explain to you how this chyle is taken up and converted into blood. Look at this diagram—it is a magnified drawing of a small portion of the lining membrane of the intestine. Thus viewed by the naked eye, it has a velvety appearance; it is covered with little hair-like projections, like the pile of velvet. Examine one of them separately—they are not more than about the $\frac{1}{30}$ of an inch in length; under the microscope they have a sort of sugar-loaf or conical form. Each of these pile-like little structures is called a villus. They are coated externally by a layer of very minute cells (little bladders). Inside this coating of cells comes a singularly-fine network of bloodvessels—a sort of lining of French cambric (if you substitute hollow bloodvessels for solid threads); within this lining you have the central rootlet of the villus. The digested food is sucked up by that canal, and carried into a tube which communicates with it. This tube is called a lacteal, or milk-like vessel. Such, then, is the structure of these villi. You will be able to form some idea of their size when I tell you that a fourpenny bit would cover about 500 of them. Let me direct you once more to my diagrams. You have seen a number of lacteal vessels running from the villi, and carrying the food they have absorbed. In the diagram they look like white worsted threads, but remember they are not threads, but tubes. As they pass along you will observe in their course certain knotty appearances,—what are these knots? These knots or

kernel-like projections are known as the mesenteric glands. The lacteals discharge the food they convey into these glands, and while detained in them a portion of it is changed. In undergoing this change it is passed through a great number of little passages—these passages are lined with small cells or bags, almost like little white raspberries—but so small that were a raspberry hollow it would contain more of these cells than there are people in the world. As the chyle or digested food is passed through the glands it is brought into contact with these little cells. A considerable portion of it is then changed into minute bodies like them, and is thus permitted to proceed on its journey to the blood. Hence, when the chyle is examined as it comes out of one of these mesenteric glands, it is found to be loaded with these little raspberry-like bodies. They are called the white corpuscles (corpuscles means a little body). Now the change the chyle undergoes in the mesenteric glands may be compared to a process for making ship biscuits which is to be seen at Portsmouth. Flour and water enter the machine on one side, and stamped biscuits come out at the other side. So chyle, which is in fact a liquid holding food in solution, flows into the mesenteric glands, and stamped corpuscles come out at their further side.

Remember, however, that the whole of the flour and water are converted into biscuits, whereas only a portion of the chyle is changed into corpuscles. On leaving the mesenteric glands, the chyle and its corpuscles continue their journey towards the blood, and after travelling a certain distance enter a little bag, a sort of storehouse of the chyle, into which all the lacteals discharge their contents. It is called the receptacle of the chyle. It is situated near the lower portion of the back bone. It has a tube attached to its upper part, into which it discharges the supplies of chyle which it receives from the lacteals. This tube passes up along the side of the back bone, and terminates at the left side of the root of the neck. There, at a spot where two large veins meet, the neck vein and the under-the-collar-bone vein of the left side, the chyle joins the blood. At the spot at which it joins, a little trap door or valve may be seen, which permits the chyle to flow into the blood vessel; but should it attempt to retrace its steps this little door would forcibly prevent it. You will now understand the vast importance of partaking of good nourishing food, for here we have the food directly entering the blood, and blood you know has been well called "the river of life."

So much, then, in regard to the chyle. I will now speak to you about the blood. I have in this jar some ox's blood. You will

observe that it is made up of two parts, a solid jelly-like mass, and a watery looking fluid. Let me explain this. If you allow blood to flow from the veins of an animal, or from one of your own veins, into a basin, and leave it to stand for a short time in a room of moderate temperature, you will find that it will separate into two parts—one part, a sticky jelly-like mass, settles to the bottom, and the other part, a straw-coloured fluid called the serum, occupies the rest of the vessel. Let me first speak of the jelly-like mass, which in books of physiology you will find termed the "clot." This clot, you will observe, is a bright scarlet colour—what gives it this colour? The microscope will teach us. Place the very smallest trace of blood on a glass slide under the microscope, and you will find that the liquid which appeared to the naked eye perfectly red, as though some dye were diffused through every portion of it, is in reality not red at all—the liquid part of the blood being nearly as white as water. To what then is the colour due, because it certainly looks red. It is due to a countless number of little red bodies, wonderfully minute like sacs or bladders, which float about in the blood and make the whole appear an evenly coloured fluid. If you pour water into a large glass jar and then fill it with red currants, you will find that at a little distance the jar seems to contain some red liquid. The blood in the same manner acquires its colour from the little red bodies which it contains. They differ, however, in no small degree from red currants. They differ in size, and they differ likewise in shape. In size they are so very minute, that if you had fingers delicate enough to handle them, you would be able to pack away some 50,000 of them, about as many as we have people in Chorlton, on the head of a pin. In such a drop as would adhere to the point of a needle, if you dipped it into blood, you would be able to count (it would be a tedious job) about 3,000,000, the population of London; and in as much blood as would fill a walnut shell there would be packed away about eighty times as many of these little bodies as there are men, women, and children, in the whole world. Now these little bodies, the red corpuscles, as they are called, give blood the appearance of being a red liquid.

I hoped this evening to have been able to show you the circulation of the blood in the web of a frog's foot. It is a most striking and beautiful sight to see blood corpuscles hurrying along like so many little ants, fulfilling the work which may be assigned to them in the body. This sight I had hoped to show you on the screen. We have not, however, as yet, succeeded in rendering it visible, but

I trust that in one of my future lectures we may be able to accomplish it. But, though I have not been able to show you the circulation in a living animal, I still have here on this slide of the lantern a small drop of blood. In it you will observe a great multitude of these little red corpuscles highly magnified. In shape they have something of the appearance of quoits, or rather what quoits would look like were their central apertures filled up. Many of you must have seen India-rubber air cushions, which, when inflated with air, very much resemble the little bodies you see on the screen—cushions depressed in the centre, but bulging out around their outer border. It is somewhat curious that these flat sides of the corpuscles have a natural tendency to adhere to one another. Hence it happens that if a drop of blood be placed on a glass slide, and examined after a short time, many of the little corpuscles will be found to be lying in rows piled together like so many sovereigns. The width of the corpuscles is about four times greater than their thickness. Hence, while about 3,500 corpuscles lying flat on their sides in one continuous line would measure an inch, it would require no less than 14,000 if they were set up on their edges. Let me now say a few words respecting the manner in which these red corpuscles are believed to be formed. You remember that I told you that the white corpuscles are formed in the mesenteric glands, and are then gradually passed on into the blood. If one of these corpuscles be carefully examined, it will appear to contain within itself another still smaller body—a sort of little kernel. In some of the corpuscles this little kernel will seem to us of a reddish tinge. From this cause the chyle, even before it reaches the blood, has at times a pinkish colour. On reaching the blood the white corpuscles throw off their outer covering, which seems to melt away in that liquid, and the little red central body is turned adrift by itself. Thus, then, the white corpuscle is, as it were, the parent of the red. It encloses and protects it for a time; and having once conveyed it to the great river of life it launches it out on the world.

These red corpuscles vary much in shape and size in different animals. In fish and reptiles they are oval or egg-shaped. In most of the animals which suckle their young they are rather smaller than in man—in the musk deer very much smaller. As viewed by the microscope there is no appreciable difference in the blood of white men, black men, and monkeys.

An acquaintance with the form of the blood corpuscles in different classes of animals may prove of great importance in criminal cases. Suppose a murder has been committed. Stains

resembling blood are observed on a knife belonging to the suspected murderer. He accounts for these stains by asserting that he has lately killed a hen or duck. The truth of his statement is readily tested. The suspected blood is moistened with a little white of egg, or other liquid of the same density as the blood. To this liquid the corpuscles, if present in the stain, will in all probability adhere, and the microscope would readily determine whether or not they belonged to the blood of such an animal as a hen. For, remember, in human blood the corpuscles are round, in hens they are oval.

A woman once came to an hospital, and stated that she had lately burst a blood-vessel, and was bleeding to death. With a view of corroborating her statement she exhibited a handkerchief saturated with blood. The doctor, before admitting her, examined the blood under the microscope, and found it not human but hen's blood. When charged with imposture, she admitted that, being anxious to be received into the wards of the hospital, she had killed a hen and soaked her handkerchief in the blood.

In every 100 parts of blood about 12 parts are composed of these corpuscles. They convey to different parts of the system the materials required for the repair of the tissues, more especially the higher organized tissues, as the nervous and muscular. They may be compared to a countless fleet of little boats, which are constantly floating along the great river of blood in our bodies. As boats convey their cargo to the place where it is needed, so these little blood corpuscles convey their contents to the tissues and organs which require them. They differ, however, from boats in that vessels after discharging their freight take in a fresh cargo, and thus ply from place to place; whereas these little blood corpuscle boats themselves perish so soon as their work is accomplished. Like man they fulfil their appointed mission, and then pass away. It has been calculated that every second full 20,000,000 of these little workmen perish—every thought which issues from our brain, every movement of our fingers alike assists in destroying them. So much then in regard to the red corpuscles which are present in the clot. So long as the blood is contained in its living vessels they are equally distributed throughout its whole mass, but so soon as it is allowed to escape from these vessels they are then found to be mixed up with the clot—the solid part into which the blood separates after standing, and they join the clot because they are somewhat heavier than the serum or liquid part. Now the clot is not composed of corpuscles alone, but consists likewise of another constituent of the blood. This constituent is called

the fibrine. It is owing to the presence of fibrine that the blood coagulates. The quantity of fibrine contained in the blood is comparatively small, not more than about two parts in every thousand, but it serves an important purpose. It may be looked upon as nature's glue,—whenever we fracture a bone or meet with any injury, even so comparatively trifling an accident as a cut finger, fibrine is poured out to unite and bring together the parts. It also enters into the composition of various tissues of the body as gristle and tendons, the cord-like bands which unite the flesh to the bones. Now there is one fact connected with fibrine which I would desire to impress upon your minds—alcoholic stimulants act upon it most injuriously. They seem to lessen its power of coagulating—they, as it were, dilute the glue. I have frequently noticed that men in the employment of brewers and distillers, who have often free access to stimulants, are bad subjects for accidents, even though in themselves trifling. Many of these men, though apparently in robust health, sink under an injury, which, had they been temperate, they might readily have recovered from, a mere scratch in some instances setting up erysipelas, and proving fatal. This is chiefly owing to the deterioration of their fibrine.

You will observe, that besides the clot we have in this vessel a watery straw-coloured looking liquid. This liquid is, as I said, called the serum—a number of different substances are dissolved in it. I will boil a little of the serum in this flask—you observe that it seems to turn white and thick. This change is owing to the presence of albumen, the same substance that you are all familiar with in white of egg. Before you boil an egg the white is clear and sticky; after it is boiled it becomes opaque and solid. The reason it becomes white is because it is composed of albumen, and it is a property of albumen to turn white and hard when heated to a temperature of 170°. Now, as the serum also contains albumen, it is natural that it should undergo the same change here that it does in the egg.

But what purpose does albumen serve when present in the blood. It must serve some useful purpose or it would not be there; and it is found there in very considerable quantities, 70 out of every 1,000 parts of blood consisting of albumen. There is some uncertainty respecting the exact purpose to which it is applied? But it seems most probable that it is a sort of liquid store of nutritive material out of which the red corpuscles are able to draw their supplies—and remember that they not only absorb this material through their coats, but, in absorbing it, absolutely change it, and thus adapt it for the higher purposes of nutrition. Before leaving the subject of albumen, I will give you a practical hint on the cooking of your

meat. If you wish to boil your meat, immerse it at once in boiling water, and afterwards allow it to simmer on a gentle fire; but if you propose to roast it, do not at first suspend it at a distance from the fire and afterwards bring it nearer, but place it at once near a very hot fire, and then you may after a time remove it further off. You will understand the reason for this advice when I tell you that the meat contains much albumen, and that the hot fire and the boiling water alike act upon it, coagulating it and making it hard. In this manner it forms a sort of coating round the meat, which assists in retaining the juices, on which its flavour depends. On the other hand, if you wish to make soup out of meat, then during the early part of the process you should never allow the water to reach a higher temperature than about 150 degrees.

In addition to the albumen the serum contains a considerable proportion of fat, this fat being thoroughly incorporated with the liquid very much as though it were soap. When the blood contains more fat than is required for keeping up the warmth of the body it is stored away in packages in sundry parts of the body, especially about the loins. The hybernating animals, which sleep during the winter months, lay up considerable quantities of fat during the summer, and burn it away in maintaining the heat of their bodies during the winter.

There is one practical remark which I would like to make before I close my lecture. There may be some among my hearers who are accustomed to spend a good deal of money in patent medicines, which you are assured in the advertisements will purify your blood and increase your chances of long life. As the promises held out to you are very tempting, you purchase life pills, and elixirs of life, and sundry other panaceas, and you confidently believe that they will go directly to the blood, and after purifying it produce in it some salutory and life-extending change. It is fortunate for you, my friends, that your digestive organs are much wiser than yourselves in the things they select for the nourishing of your bodies. Hence the greater portion of the nostrums you purchase do comparatively little harm, except in so far as they rob you of your money. Do not imagine for a moment that the persons who sell you these purifiers of the blood, place any great confidence in the virtues of their drugs. They do not partake largely of them themselves, but they convert the money they receive from you into beef-steaks and mutton chops, and purify their own blood on them. You cannot do better than follow their example. Simple, wholesome food, and temperate habits, conduce more effectually to good health and long life than all the quack medicines which were ever invented.

FOUR LECTURES

ON

ELEMENTARY PHYSIOLOGY.

LECTURE III.

THE BLOOD (CONCLUDED) AND THE CIRCULATION.

Brief recapitulation of Last Lecture. Mineral substances contained in the blood—Gases in the blood—Quantity of blood in the human body—Difficulty of estimating the quantity of blood. Transfusion.—How is the blood distributed to the tissues? The blood vessels—the arteries.—Structure of the arteries—the capillaries.—The veins—The veins terminate at the heart.—The heart divided into four chambers—The valves of the heart—Course of the circulation through the heart—Sounds of the heart—Heart's beat.—Arterial blood changed into venous in the capillaries.—Restless activity displayed by the blood.—Noiseless manner in which the heart works.

Before I proceed with the present lecture, allow me to remind you in a few words of what I told you in my last. You will remember that I spoke to you of the chyle, and likewise of the blood. I told you that the chyle was food which has passed through certain changes in the mouth, in the stomach, and in the duodenum, whereby it is rendered soluble, reduced in fact into a liquid pulp—and so in a fit state to be absorbed by certain little rootlets distributed along the course of the bowels. These little rootlets are known as the "villi." I told you that if you examined closely the lining of the intestine, you will observe that it presents a velvety appearance—that it seems in fact covered with a sort of pile—the little hairs which resemble a pile, when viewed under the microscope, are found to consist of conical or sugar-loaf shaped projections. You will find that they contain within them a very

minute root. It is into this little root that the chyle passes, being sucked in by the action of endosmosis. I told you that the roots of the villi communicate with a set of vessels called the lacteals, so called because when distended with chyle they look as though they contained milk. Along the course of these lacteals are numerous knotty kernels, termed the mesenteric glands. On entering these glands the chyle is merely food in a liquid form, but on leaving them it is found to have undergone an important change. It then contains a vast number of very minute bodies, which I told you look under the microscope not unlike little white raspberries. These are the white corpuscles of the chyle. On leaving the mesenteric glands the chyle and its corpuscles are conveyed to a little bag (the receptacle of the chyle) and discharged into it. At this receptacle the different lacteals terminate—a tube passes from its upper border in a direct line to the root of the neck, and there joins the great vein which runs under the collar bone on the left side. At this spot the chyle is emptied into the current of the blood. After making some remarks on the chyle, I proceeded to speak of the blood. I told you that if you allowed blood to flow into a vessel and left it to settle, it would divide into two parts, one a jelly-like mass, known as the "clot," the other a watery fluid, called the "serum." I first spoke of the clot and told you that it thus coagulates because the blood contains within itself a certain constituent termed fibrine—a substance, which in living blood vessels is perfectly liquid, but when separated from them gradually thickens and becomes a clot. The fibrine I spoke of as nature's "glue" is always ready to unite the two surfaces of a wound, whether that wound be a fracture or a simple cut. I told you that the clot was red, because in coagulating it entangles within its meshes certain very minute red bodies—so small that no fewer than 50,000 of them could be packed on the head of a pin. I told you that these little red bodies are the corpuscles of the blood. Taken singly they are altogether invisible to the naked eye—but when viewed in the mass they give to the clot a uniformly red appearance. You will remember that I next drew your attention to the fact, that many of these little red corpuscles are formed out of the white corpuscles whose origin we traced to the mesenteric glands. They are the most important constituent of the blood. Thus we followed the several processes by which food is converted into blood, certain parts of it being changed into white corpuscles, which contain within themselves the germs of the future red corpuscles. I then proceeded to speak of the "serum," the fluid in which the clot was seen to float. On boiling a small quantity

of this serum I showed you that it became white, the reason being that it contained a certain proportion of albumen—the substance you are all familiar with in white of egg. I told you that there is in the blood a large quantity of this albumen, which may be looked upon as a sort of reserve store of nutriment for the supply of the red corpuscles; and, finally, I spoke of the fatty materials which, in the form of a soluble soap, enter largely into the composition of the blood.

Before proceeding to the circulation of the blood, I will now make a few observations on the minerals and gases which, in addition to the constituents I have already enumerated, are, as it were, stowed away in the blood. Of these minerals our tissues contain a very considerable proportion. This I might prove to you by the following experiment:—Suppose we choose a man of the average size—one willing to sacrifice himself in the cause of science—we proceed to pound him up in a mortar, and then analyse the constituents of which he is composed. What should we find? Why we should discover that at least ten per cent of these constituents would consist of mineral substances: we should get lime, and iron, and sulphur, and flint, and phosphorus, and many others. Now if these substances are present in the tissues, they must also be present in the blood, because the tissues all feed on the blood, and draw their supplies from it. But you may ask how do they get into the blood? How, for example, does such a substance as lime, with which we are all familiar as a hard white substance, find its way into the blood, and how does it afterwards reappear in the form of bones and of teeth? Let me endeavour to make this clear to you. Though lime gets into the blood, still it does not enter it as a solid, nor does it there exist in the form most generally known as lime, but it is dissolved through the blood. Look at this tumbler which I hold in my hand: you see nothing in it but a white fluid like water, and yet an eggshell is dissolved in it. Having added a few drops of muriatic acid to this water before beginning my lecture, I placed an eggshell in it which has totally disappeared—it is, in fact, dissolved in the liquid. The lime is still there, but it is not there in the visible, tangible form in which we are accustomed to see it. In a similarly liquid form lime is diffused throughout the blood; and wherever it is required in its solid form it is given out by the blood to the part in need of it. When, for example, it is required in the form of a bone or a tooth, the blood lays it down at the exact spot at which it is wanted, in the shape of minute little solid particles called bone earth. Layers of this bone earth are spread out within

and around the bone. This will enable you to understand the manner in which bones grow. Let me give you a familiar illustration of a similar kind of process. You must often have noticed in walking under an arch, long pointed-looking white needles, suspended over your head, with the points turned downwards, in shape like icicles. What are these needles? They are called stalactites, and are thus formed. The arch contains lime in its mortar; water trickles through this lime, dissolves a portion of it, and hangs downwards as a drop; the water is given off to the air in the form of invisible vapour, and the solid lime is left attached to the arch. Thus you have a solid bone-like substance formed from lime dissolved in water—just as in our own bodies bones are formed from the lime dissolved in the blood. You are doubtless aware that various articles of food contain considerable quantities of lime. If the food of young children is deficient in lime their bones will not grow hard and compact, but will give way and become distorted. This is what happens in the disease known as rickets, instances of which we see far too often in our large towns. Why do we see them? Because you parents, in your folly, do not feed your children on the food which nature intended them to have. Nature intended all infants to be fed on milk; but you consider yourselves wiser than nature, and give them a great variety of messes—sago and arrowroot, and tapioca and potatoes. From this food they cannot get the lime which milk would have supplied to them in abundance, and the consequence is that when they begin to walk you have the painful mortification of seeing them grow up as cripples—of seeing crooked legs and arms, or stooping shoulders and wry necks, where, had nature been allowed full sway, she would have given straight and stalwart forms. I here show you some bones which have been placed for some time in a jug of water acidified by muriatic acid. You will observe that they are so soft that I can tie them in knots, as though they were pieces of hempen cord. The reason they are soft is because they have been deprived of their lime. Now remember what I have told you respecting lime is equally applicable to all the other minerals in the body—they are all dissolved through the blood.

You may ask me what becomes of these substances when they are dissolved. How and where are they packed away? This is a question which, with the knowledge we possess, it is not easy to answer. Let us observe, however, what takes place when a substance like salt is added to water. We find that we can add to a given quantity of water a certain proportion of salt, without increasing the actual bulk of the water. We make the water

heavier, but up to a certain point we may add salt without augmenting its volume. Perhaps we may explain this disappearance of the salt by supposing that the ultimate atoms of water consist of very minute particles which are hollow inside, and permit the substances which are dissolved in the water to pass into them by a sort of endosmotic action. Before leaving the minerals of the blood I would make one practical remark. You are aware that many of these substances are given as medicines. There is reason, perhaps, for believing that the blood is deficient in some one or other of them, either in its iron, or its lime, or its potash, or soda. It is the province of those who devote themselves to the healing art to discover wherein this deficiency consists, and to endeavour to remedy it. Thus, when the cheeks look pale and bloodless iron is given. In such a case it is presumed that the blood is deficient in red corpuscles. Iron is known to enter into the composition of the red corpuscles. It is therefore administered as a medicine in order that these little bodies may have an additional source from which to draw their supply. In the same manner sulphur, phosphorus, magnesia, soda, and potash are all given as medicine. Many of the most famous mineral springs owe their celebrity to the fact that their waters contain these very minerals. Several of the German wells, which are at present frequented by the sick of all nations, were famous even in the time of the Romans. Some of these wells contain iron, others sulphur, and others magnesia, and potash, and soda, dissolved in their waters. Many persons, when medicines such as those which I have enumerated are given to them, think that they are taking something altogether foreign to the tissues and organs of which their bodies are formed. From what I have said, however, you will understand that minerals, and more especially those minerals which are found in the blood, may with as much truth be spoken of as food, as bread and butter, and meat and potatoes. For if you exclude from your dietary all mineral food you will as certainly die as if you exclude all flesh-forming food. But not only does the blood hold mineral substances in solution, but gases likewise are contained within it. How, you may ask, is this possible? I will endeavour to make it clear to you. If you fill a quart measure full of blood, so full, in fact, that it can contain not one drop more, then you know that if you were to add any more liquid to that vessel it would run over. If, however, you introduce into the lower part of the vessel a tube attached to a bladder containing one pint of gas, say a mixture of carbonic acid, and oxygen, and nitrogen in certain proportions, you will find if

you perform the experiment with care, that the gas will disappear in the blood, it will in fact be dissolved through the blood, just as I told you that salt and sugar are dissolved in water. In sodawater you have a familiar illustration of the presence of a gas in a liquid. In the making of sodawater more gas (carbonic acid) is forced into the water than it can contain in the open air (it does contain it, however, so long as it is in the bottle, by reason of the pressure of the cork), but the moment the cork is allowed to escape the gas and the water come gushing out, and then the sodawater is said to effervesce or "fizz." If you now allow it to stand you will find that in a short time the effervescence will entirely cease, though there is still gas in the water. In the same manner that gas is dissolved through the water you have gases dissolved in the blood, and a very important purpose they serve. Now, what are the gases which are present in the blood? They are the same that I spoke of as present in the air, but in very different proportions. In the air we have about $\frac{4}{5}$ of nitrogen, $\frac{1}{5}$ of oxygen, and a comparatively small quantity of carbonic acid. In the blood, on the other hand, we find about $\frac{2}{3}$ of carbonic acid, $\frac{1}{3}$ of oxygen, and $\frac{1}{10}$ of nitrogen. Thus, in every quart of blood there is dissolved about one pint of these three gases in the proportions I have stated; carbonic acid, the gas you are familiar with in sodawater, is the most abundant of the three; oxygen, the active gas of the atmosphere, is the next most abundant; and nitrogen, the inert gas of the air, is only present in very small quantities.

Allow me now to say a few words in regard to the quantity of blood contained in the body of an ordinary sized man. Various attempts have been made to decide this question, but it has been found beset with difficulties and is not readily settled. You are probably aware that in some parts of the continent murderers are not executed in the same way as in this country. Here we hang the worst of our felons—there they decapitate them—cut off their heads. Now it occurred to some of the scientific men of these countries that by weighing a criminal before execution and by afterwards weighing the head and trunk, they would, in the loss of weight, ascertain approximately the quantity of blood. Although these investigations were conducted with great care it was still found that there were wide variations in the quantity of blood lost by different persons—some losing upwards of twenty pounds, and others not more than six or seven pounds. The reason these different persons lost each varying quantities of blood may be partially explained by the fact that all animals are

able to sustain the loss of far more blood when they are digesting their food than when they are fasting. Thus, if the veins of two sheep (one of which is fasting, while the other has lately been fed) are opened at the same time, and if they are allowed to bleed to death, it will be found that the fasting sheep will die after parting with little more than half the quantity of blood which will prove fatal to the lately-fed sheep. This might be a useful physiological fact for a general to remember on the morning of battle—a good meal before fighting would save the lives of many men who would perish from the loss of blood were they wounded when fasting. But although it is impossible to estimate with any degree of accuracy the exact quantity of blood contained in the body of a full-grown man, we shall not be very wide of the mark if we say that on the average it will probably amount to about 12lbs. There is one more remark I would make respecting the blood. It is this—if good healthy blood is so all-important to each one of us, would it not be possible, when we suffer from sickness, to procure a small portion of the blood of some robust person, and to have it injected into our veins. This was a favourite idea of the ancients:—it seemed so simple and natural! It was revived so lately as last year as an infallible cure for the cattle plague. I need not tell you that like every other so-called "cure" it miserably failed, and the reason it always has failed, and in cases of sickness always will fail, is because even though blood be healthy unhealthy tissues are unable to avail themselves of it. It is by reason of this change in the tissues that young blood exercises no beneficial influence when it is transfused into old veins. For not only have people at various periods of the world's history thought that it would be a desirable practice to cure diseases by means of healthy blood, but they have also thought that in the same manner old people might be made young, and this surely would be an agreeable achievement for a doctor to accomplish—to make some poor old shrivelled lady of eighty look and feel once more as she did at twenty. Well, the attempt has often been made, but it has failed signally—and it has failed because while there is no appreciable difference between the *blood* of the old and the young there is the widest positive difference in their tissues.

But, although I have not spoken to you very encouragingly on this subject of "transfusion," as the passing of one person's blood into another person's veins has been called, I am still bound to admit that there are cases where the practice is likely to be attended by the happiest results, and they are these—when it is

had recourse to, not with a view of curing sickness, but because death is approaching with rapid strides from actual loss of blood. suppose one of you were to lay open a large artery, and to experience a great loss of blood, by the time the doctor arrived and tied the vessel you might have parted with so much of your blood that there would not be enough for the heart to contract upon. Under these circumstances, if left to your fate, you would infallibly die; but should a friend, out of affection for you, spare you a small portion of his blood, then the probability of your recovering would be very great. In this manner we can imagine that a considerable number of lives might be saved in a battle, if an army of volunteers were willing to share their blood with the brave defenders of their country who were bleeding to death from their wounds.

Having said thus much respecting the blood itself, let us next consider how the blood is distributed to the different parts of the body. If the different tissues and organs stand in such constant need of the blood there must be some special apparatus whereby it is distributed to them. Let me explain this apparatus. In the upper portion of the trunk there is a powerful forcing pump called the heart, from which pipes are distributed to all parts of the body—one set of pipes carrying blood from the heart, and another set of pipes bringing it back to the heart. In fact, you have in the body the same sort of apparatus that you have in a well-fitted house. In a well-furnished house you generally find a boiler in the kitchen, and from the upper part of this boiler a pipe conveys the hot water to the upper stories of the house, while a return pipe, communicating with the lower part of the boiler, completes the circulation of the warm water through the building. Let us now see what are the pipes by which the circulation of the warm blood through the human house is effected. You see here (pointing to a large coloured diagram of the body) the pipes which carry away the blood *from* the heart. These pipes are called the "arteries;" the word artery signifies "air container." The ancients, when they examined these vessels after death, found them empty, and hence supposed that they contained nothing but air. Here you see the great artery of the body passing directly from the upper part of the heart, and bending backwards till it comes in contact with the spine, travelling on for some distance along the backbone, and then dividing into two great trunks which pass down into the legs. Let me now say a word respecting the materials which are found in the coats of these arteries. These coats are not made throughout of some one substance, as, for example, gas pipes are made of lead; but they are made of

different materials woven together, so that you have in fact several coats, one of which is elastic, while another is contractile. Do you know the difference between elastic and contractile? When a substance is elastic it rebounds—it returns with a sort of spring to its original size whenever it is stretched or drawn out. Elasticity is, you know, a property of India-rubber; on the other hand, a tissue is spoken of as contractile when it presses upon its contents, or draws together its sides without having first been made larger. Thus the one has to be pressed upon or pulled out, and then contracts; the other contracts without having been pressed upon. Both these substances—the elastic and the contractile—are found in the coats of the arteries. Besides having these two coats, the interior of the arteries is smoothly paved with little cells, which allow the blood to flow as easily over them as though they were encaustic paving tiles.

Let us next consider how these arteries end—that is a question which must often have occurred to you. It puzzled the old physiologists not a little, who did not possess the microscope (an instrument which has done so much for us) to assist them in their inquiries. They followed these vessels as far as they were able to see them with the unassisted eye, and then, when they could no longer see them, they concluded that they must have terminated in small open mouths. By these little mouths they thought that the blood was emptied into the tissues, which then helped themselves to what they might require. Nature, however, does not finish her work in this slovenly sort of way. Let us therefore see how these little vessels finally terminate. After becoming invisible to the naked eye they still pass on for a considerable distance as arteries; they still have the three coats of which I have told you; and then they empty themselves into a very minute network of the finest muslin, only you must remember that the threads of this muslin, instead of being solid threads, consist of the minutest little tubes. These tubes (the capillaries) are spread out in different directions. Sometimes you would think that the meshes on which they are, as it were, formed were long and thin; at other times they seem to be round. In some parts of the body these capillaries actually occupy more space than the tissues they nourish. These little tubes are called capillaries or hair-like vessels, though they are in point of fact as much smaller than hairs as hairs are smaller than cables. You may imagine how numerous they are when I remind you that it is impossible to prick yourself in any part of the body without rupturing some of these vessels. Many of these capillaries are so

small that 5,000 of them placed side by side would not in their united width measure more than one inch. Others, again, are considerably larger, but on the average they are not more than about the $\frac{1}{3000}$ of an inch in diameter. In what is called the white of the eye you can occasionally see them—not when the tissues of the eye are in a healthy state, but when they are inflamed and the little capillaries are crammed full of red blood. Remember then that at the termination of the arteries—the vessels which carry the blood from the heart—there is a network of these very minute capillaries. Now how, you may ask, is it possible, even with a microscope, to tell where the arteries end and where the capillaries begin? You distinguish between the two sets of vessels, even independently of the difference in size by their coats The arteries have, as I have told you, several coats; the capillaries have only one, and this coat is formed of much the same material as the coats of the little blood corpuscles. I will now show you some of these capillaries on the screen. [Dr. Morgan illustrated this portion of his lecture with several highly magnified diagrams, which were exhibited on the slides of a magic lantern fitted with the oxyhydrogen light, exhibiting these minute structures by their aid more clearly than is possible with unaided type.] You will now wish to know what becomes of these little capillary vessels? How and where do they end? They end in another set of vessels called the veins. If you follow the capillaries for a certain distance you will find that they end in another set of vessels—the veins—and just as the arteries, before they join the capillaries, grow gradually smaller and smaller, so does this other set of vessels, commencing in the capillaries, grow continually larger and larger. These vessels are, as I have told you, the veins. What are the veins? They are the return pipes that bring the blood back to the heart. Like the arteries they differ from the capillaries in having several coats; but in these coats there is comparatively little of that elastic tissue which enters so largely into the coats of the arteries. As the red lines in the diagram represent the arteries, so the blue lines stand for the veins. The two sets of vessels are painted a different colour, because the blood they contain also differs in colour. In the arteries it is a bright scarlet, while in the veins it is almost black. Many persons when they see black blood imagine that it indicates some peculiarly unsatisfactory state of the system. They are not aware that venous blood or the blood of the veins is always black. Let me now follow the veins in their course and see where they terminate. You will observe that the veins of the lower extremities travel

upwards, constantly becoming larger by the junction of additional branches, until at last all the united branches terminate in one trunk at the heart. The branches proceeding from the arms and head in like manner terminate in a single trunk, which also joins the heart. Thus all the blood which the heart receives from the different organs and tissues of the body, with the exception of that which comes from the lungs, enters it by two great venous trunks, the one descending from the head and upper extremities, the other passing up from the legs and lower portions of the trunk. Having said thus much respecting the pipes which carry the blood from and to the heart, let me now speak about the heart itself; and let me remind you that though people are always talking about their hearts, and attributing all sorts of diseases to this mysterious organ, it is wonderful how few are able to point out the exact region in which it is situated. My hospital patients frequently come to me and tell me that they have a pain in their heart, but when I ask them to point to the spot they place their hands over a very different region; and even well informed people have an idea that the heart is situated more decidedly to the left than it really is. Look at that diagram, the heart there occupies its natual position, and you will observe that it is as it were hung almost in the centre of the breast, certainly a very considerable portion of the organ is actually covered by the breast bone. The lower portion, however, does incline towards the left side, where it may be felt to beat between the fifth and the sixth ribs. Having pointed out to you the situation of the heart, let me next speak of its size. You may form a pretty correct idea of the size of your heart by doubling your fist. It may be stated generally, with considerable approximation to the truth, that a man's heart corresponds pretty closely in size with his closed fist; and, as people's fists are usually proportionate to their size, so are their hearts. In shape the heart is probably as like the cocoa nut as anything else to which I can compare it. If you have been accustomed to get your ideas of its form from the gorgeous representations which figure on the valentines, I fear your notions on the subject will not be very correct. But even these representations may serve a useful purpose if they remind you of one important fact in connection with the heart, and that is, that it is to all intents and purposes a double organ; down the centre of it, from top to bottom, runs a partition wall, which altogether separates the right side from the left. In fact the heart may not inaptly be compared to a semi-detached house—to two houses with one common wall passing round both, but separated by a partition, which precludes all direct intercommunication. Let us examine

separately each semi-detached heart, first the right side, and then the left. Now, not only are these two sides of our heart separated by a wall, but each side is further divided by a partition stretched across it. Owing to this partition we find in each side of the heart two chambers, an upper chamber and a lower chamber; in the partition on the right side of the heart there is a door—a very perfect and beautiful contrivance—which works on much the same principle as the gates of a canal lock. You know that canal gates are constructed in such a manner that the water is only permitted to flow in one direction. It is the same with the heart; the blood can flow through from the upper chamber into the lower, but it cannot pass in an opposite direction from the lower into the upper. When it attempts to do so the three-leafed folding doors which surround the aperture close and prevent it. These doors are not formed of a hard substance like the gates of a lock, but of a fibrous material like canvass. You might object to such a material being used, and think that stiff-sided doors would be better because they could not be turned inside out. Nature, however, has met this objection by attaching very fine cords all over these canvass flaps. These cords are fastened to little fleshy pillars that rise out of the walls of the heart—and as soon as the doors are closed a tension is thrown on these cords, and hence they cannot be carried beyond a certain point. I have here an ox's heart, which will give you a very good idea of these structures as they are seen in man. Now, although the blood is not permitted to flow from the lower chamber into the upper, yet it finds egress through another door situated in the roof of the lower chamber; this door, however, differs from the one I have described, in not opening inwards but outwards. This door, on the right side of the heart, communicates directly with a tube which sends off branches to both the lungs. Round the opening of this tube there are three little niches, actual depressions in the coat of the tube, and attached to these depressions hang three little bags. When the blood flows out at the door these little bags hang empty within their niches, but the moment the blood tries to return they bulge out and fill the aperture, looking like three egg cups placed side by side. I here show you three of these little bags. They are taken from the large artery which passes from the right side of the heart into the lungs of an ox. [Dr. Morgan further illustrated this part of his subject by some magic lantern slides, exhibiting the position of the valves.] Such, then, is the structure of the right side of the heart. The left is in every respect like it, except that the aperture leading from its upper to its lower chamber is closed by a

two-leafed instead of a three leafed folding door. Having now described the system of pipes by which the blood is distributed, and likewise the structure of the forcing pump by which these pipes are supplied, let me say a few words respecting the blood in motion—actually circulating through the vessels. I will commence at the heart; and we will suppose that the great veins of the body have just emptied their black blood into its right upper chamber—its receiving cistern. The walls of this chamber instantly contract, and the black blood is then passed on into the right lower chamber—the forcing pump of this side of the heart. As this chamber presses forcibly on its contents, its folding doors, which admitted the blood from the upper chamber, are closed, and their cords stretched, while the door in the roof throws back its bags and gives free egress to the swiftly moving current. The black blood is now carried into the lungs, passed along narrower and narrower tubes, till it at last enters the capillaries of the lungs. In these vessels (the length of which if united would extend for miles upon miles) it is, as it were, spread out to be purified. Being exposed in them to the action of the air for a few minutes it loses its dark shade and returns to the heart of a brilliant scarlet colour; but it does not return to the side from which it came. It passes now to the left side, the side which receives and distributes the pure blood, as the right side receives and distributes the sewage blood. Here it enters the upper left chamber, passes from thence to the lower, and is then forced out by the left upper door to the great artery which forms the main trunk of the river of life, and supplies the different organs and tissues with their sustenance. Thus, every time the heart contracts, we have, as it were, two distinct circulations. The one from the lower right chamber to the upper left (the object of this circulation is the purification of the blood), and the other from the lower left chamber to the upper right. In the course of this circulation the blood nourishes the body, but becomes itself laden with impurities. [Dr. Morgan then exhibited on the screen a diagram of the circulation, showing both the systematic and pulmonary circulation. The circulation in a fish's tail was also shown upon the screen.] As the blood is forced from the left side of the heart it first enters the arteries, and passes from them into the capillaries, and it is here that nutrition goes on. In the capillaries you have a fluid of one density, and in the tissues without them you have a fluid of another density, and wherever two fluids of a different density are separated by a thin animal membrane there an interchange is set up, the thinner liquid passing readily to the thicker, while at

the same time the thicker passes somewhat tardily to the thinner. But as nutrition goes on at the capillaries, so it is here that the colour of the blood is changed from scarlet to black. When the blood enters the capillaries it is scarlet, when it leaves them it is black. This change in colour is due to the fact that the red corpuscles of the blood, the oxygen carriers as they have been called, give out a portion of their oxygen, and take in its place a certain quantity of carbonic acid. Coincidently with this change in their contents the corpuscles undergo a change in their shape likewise. In the arteries, where in the mass they have a scarlet colour, they incline to a flat shape, while in the veins their shape is rather round than flat. Oxygen gives them their flat shape, and carbonic acid their round shape. When the corpuscles are flat they reflect the light that falls upon them, and so look red; when they are round they allow the light to pass through them, and so in the mass appear black.

As the heart is performing its work it gives out certain sounds. If any of you have listened to the beating of the heart, you will have heard these sounds. They differ from the ticking of a watch, in that one of the sounds is longer than the other. The first of the heart's sounds has been compared to the word "lubb," that is, a prolonged sound; while the second, which is much more sharp and rapid, has been likened to the sound in the word "dup." These two sounds are succeeded by a pause. Thus you have a long sound and a short sound, and a pause, succeeding one another with perfect regularity from the first moment of our lives even unto their final close. When the walls of the heart contract and force out its contents, then arises the first sound, and when the doors close, then is heard the short, sharp, second sound.

As regards the forces by which the blood is propelled through its vessels it is proper that I should say a few words. First and most important is the impulse communicated by the contraction of the heart itself; then when the blood is forced into the vessels the elasticity of the arteries comes into play. The blood forcibly propelled into its vessels by the heart distends their coats. When the heart ceases to contract and pauses, the elastic tension possessed by the coats of the vessels re-acts on the blood; and inasmuch as the blood is prevented from returning into the heart, it is necessarily forced on along its vessels. When the elastic tension has spent itself, then the contractility of the arteries is called forth, and so an additional impulse is given to the blood on its passage to the capillaries.

Such, then, is the structure of the heart, and after this manner is the circulation of the blood accomplished. From what I have

said, I think you will agree with me in thinking that the heart is a very wonderful piece of mechanism. Here we have these two lower chambers of the heart contracting and propelling the blood along the arteries with a force which has been calculated as equal to a pressure of nearly 7lbs., and they continue to exercise this force day and night without cessation. With no other set of muscles could you get through the labour which the heart achieves; for remember, that if you are to make the comparison between the heart's labour and the labour you accomplish with your hands—a just one, it would be necessary that you should work during the night as well as during the day; and not during the night alone, but also during the hours that you rest your hands at meal times, and during the hours you devote to recreation and rest; for, bear in mind, that so long as life lasts the heart never gets one moment's repose.

Another thing which must impress you is the noiseless manner in which the work is done. And this remark applies not alone to the heart but likewise to several of the other organs. In our bodies we have pumps and churns and chemical laboratories all at work at one and the same time; and yet so quietly do they get through their work, that, so long as our health continues, we actually are unconscious that any work is being done.

Table showing the average proportions of the constituents of the blood in 1,000 parts:—

Water	784
Red corpuscles	131
Albumen.	70
Fatty and extractive matters	6·77
Saline matters	6·03
Fibrine	2·2
	1000

FOUR LECTURES

ON

ELEMENTARY PHYSIOLOGY.

LECTURE IV.

BREATHING, AND THE ORGANS WITH WHICH WE BREATHE.

SITUATION of the lungs—Structure of the lungs—The larynx—The wind-pipe.—The lung tubes—the air sacs—the air cells.—The artery of the lungs. The Chest.—Its shape—its movements.—Floor of chest. The air we breathe.—Breathing the function of the lungs, by which blood takes in oxygen and parts with carbonic acid.—Loss of oxygen is respired air.—Oxygen goes to red corpuscles.—Oxygen given out at capillaries. Animal heat. Quantity of carbonic acid in respired air. Quantity of water in respired air. Suffocation.—Instances in which numerous deaths have arisen from suffocation.—Ventilation.

I AM going to speak to you to night, my friends, about breathing, and the organs with which we breathe—the lungs,—but before I turn to my subject, allow me to remind you of what I told you in my last lecture. With regard to the circulation of the blood I told you that the blood is distributed to the different organs and tissues of the body by a complete system of pipes; that one set of these pipes carried the blood from the heart, and that another set of pipes carried the blood to the heart; that those which carry the blood from the heart are called arteries, while those which carry the blood to the heart are called veins; and that between the extremities of the arteries and the commencement of the veins we find another very minute set of vessels called the capillaries.

These capillaries therefore connect the arteries with the veins. I then went on to speak to you about the heart; pointed out to you on the diagrams the situation of the heart, behind the breast bone, nearly in the centre of the chest, and told you that it was divided into four chambers; that the blood was brought to the heart by two large veins, one passing up from the lower extremities, the other coming down from the head and the upper extremities. These veins empty themselves into the right upper chamber. From the right upper chamber the blood is passed into the right lower chamber, and is thence driven by the contraction of the walls of the heart into an artery which terminates in the capillaries of the lungs. The capillaries of the lungs communicate with veins, which finally discharge their contents by four separate trunks into the left upper chamber of the heart. From the left upper chamber it finds its way into the left lower chamber, and is then pumped out into the great artery which distributes its branches to the different organs and tissues of the body.

Let me now speak to you of the lungs and the chest; and in dealing with this subject I will proceed in the same way as I did in my lecture on digestion. I first described the structure of the stomach, and then spoke of its functions, or the manner in which it does its work. What, then, are the lungs, and where are they situated? you see them well painted in that diagram. You will observe that in man there are two lungs—one on each side. The right lung is divided into three parts called lobes, and the left into two. They are situated one on each side of the heart, and are surrounded by the ribs. The lungs communicate with the outer air by the nostrils, and by the mouth: the nostrils are the aperture of the lungs, as the mouth is the aperture of the stomach. You know that a cold in the head when the inner lining of the nostrils is thickened, often passes down into the chest, thus showing that the two are closely connected with one another. The passage, however from the nostrils to the lungs is not altogether a perfectly direct passage. It is pretty continuous till it reaches the back of the tongue, but then enters a narrow aperture immediately under the roof of that organ. This aperture is guarded by a self-opening spring door: when food is swallowed this little door is tightly closed until the contents of the mouth have passed its threshold, and then it swings back its leaf and remains open till the act of swallowing is repeated. If in swallowing you burst out laughing this door is forced open at a time when it ought to be closed, and then food is apt "to go the wrong way." Within this door you will find an aperture, a narrow chink formed by two cords. They

are the voice chords. They are stretched across a little box (the larynx) popularly known as Adam's apple. They are called the voice-cords, because when the air from the lungs is forced through them their edges begin to tremble, until vibrations of sound are given forth. Voice originates in these cords; when they are destroyed by disease it is only possible to speak in a whisper. Below the voice cords, immediately under the so-called Adam's apple, we come to the windpipe. In front and at the sides it is surrounded by rings, formed of gristle, which do not, however, meet at the back. Although this tube is called the windpipe a great many people have an idea that the food they swallow is carried to the stomach along this passage. That is not the case; the food passes along a distinct tube situated at the back of the windpipe. If the windpipe was not protected by rings, the passage into the lungs might be closed when we stoop, and the air would be prevented from entering them. Soon after the windpipe enters the chest it divides into two large branches, called the bronchial tubes. One of these branches passes into the right lung, and the other into the left. In the lungs they subdivide into a great number of smaller branches. For a considerable part of their course these tubes, which are composed of a tough and partially elastic material, are strengthened and kept open by little rings of gristle. These rings, however, differ from the rings found in the windpipe, in completely encircling their tubes. As the tubes pass on they get continually smaller and smaller, and as they diminish in size, they lose their rings, until at length they are almost entirely composed of a fine elastic material. These tubes terminate in very minute sacs or bags, the end of each tube being attached to one of these little bags, as though they were so many hollow berries. Let us examine the interior of one of these bags; they are called lobules or air sacs, and are traversed by sundry little passages. Both these passages and the walls of the air sacs are surrounded by a vast number of little partitions, which project from their sides, giving them, under the microscope, a sort of honeycombed appearance. It has been calculated that in each air sac there are no fewer than 18,000 of these little partitions, and that the lungs of a grown-up person contains about 600 millions of them. These partitions are known as the air cells of the lungs.

The air sacs and their cells are the parts of the lungs which especially suffer from that terrible disease which kills such great numbers of our race, which you are all familiar with under its well-known name—consumption. Although the air cells are so small that they are altogether invisible to the naked eye, we should still

find that, were it possible to spread them all out in one continuous piece, like a roll of calico, they would measure 300 yards, the material being about one yard in width through its entire length.

Let me now say a word regarding the manner in which the bronchial or air tubes are lined. Nature has a particular material of its own, which it applies to lining, covering, and sundry other purposes. In books of physiology you will find it spoken of as epithelium. Let us examine this epithelium under its simplest form. In its simplest form it looks like a little bladder or sac, but as it is required for different purposes, so it takes different forms. It is out of this epithelium that the skin is formed. You know that our muscles do not come into direct contact with the outer air, and it is fortunate for us that they do not. In this diagram you see the different muscles of the body denuded of their skin and the tissue below it. You must admit that the appearance of such a figure is singularly unsightly in comparison with what we are accustomed to admire in "the human form divine." The difference is mainly due to the absence of the skin. This skin is formed of epithelium. If you examine the under skin you will find that it is made up of layers upon layers of little cells or sacs, which look under the microscope almost like so many soap bubbles. As these little sacs approach the surface they become flatter, until finally, when they terminate at the skin, they are merely dry scales. They then constitute one continuous waterproof covering, the scales lying side by side all over the body like so many little slates. So long as they are round and contain a liquid secretion, they are tender to the touch, but when they become scaly they can endure pretty hard knocks without our experiencing any pain. This same epithelium lines also the arteries and veins, and is laid down all around their coats like so many little tiles. In this manner it makes their inner surfaces perfectly smooth, so that the blood can easily travel along their tubes as though they were glazed. This same epithelium covers also the villi of the intestines, whose structure I have so fully explained to you; but here, instead of being flat, it takes the form of little pears set up on end all over the villi. When applied to another purpose the cells of epithelium are drawn out into fibres which are, as it were, woven into hair, and then we admire it in the wavy and glossy covering of the head. But, interesting as are these different forms of epithelium, perhaps the most curious form of all is that which it assumes when it is used as a lining for the air tubes. Here rows upon rows of little round cells are laid down within the tubes, till at length the innermost cells lengthen themselves out,

and seem to stand on end. These upright cells lie, as it were, wedged in by their neighbours on every side, except where they face the air tube. Several very minute little projections, not unlike fine hairs, arise from these surfaces. As the cells stand side by side, these little hairs form one continuous brush, which constantly sweeps the sides of the tubes. Day and night these busy little workmen ply their brooms. Whenever minute particles of dust enter the lungs, or mucus is formed within them, it is brushed out in the direction of the windpipe and forced out with a sudden blast of air, which we call a cough. These, then, are the brushes which nature uses for the dusting of the lungs. Not content with fulfilling the duty required of them through life, they may even, for a short time after death, continue their movements.

Let us next proceed to speak of the great artery which discharges its blood into the lungs. This artery is called the lung artery, and proceeds from the right lower chamber of the heart. You will remember that in speaking of the heart I told you that a large vessel proceeded from the roof of the right lower chamber; well, this is the vessel to which I then referred. Soon after leaving the heart it divides into two branches, one of which passes into the right lung, and the other into the left. For a time these vessels run by the side of the air tubes, like them becoming smaller and smaller until they reach the air cells. Here they send very fine branches round each little air cell, while these branches, fine as they are, send out still finer branches (the capillaries of the lungs) into the very partition walls of the air cells. These capillaries here are so close to one another that they actually occupy more room than the interspaces between them. I have calculated that could the capillaries of the lungs be all united together so as to form one continuous tube, this tube would measure about 5,000 miles: it would be more than long enough to reach to America and back. If you examine these little vessels in the lungs you will find that their sides project beyond the walls of the air cells, looking not unlike the veins of a fine leaf when it is held up to the light. After covering the walls of the air cells with thin delicate branches, the capillaries, here, as in the rest of the body, end in veins, and these veins, like all other veins, as they travel onwards towards the heart, get gradually larger and larger, until at length they end in four trunks, all of which discharge their contents into the upper left chamber of the heart. Thus you will observe that there are in the lungs a number of tubes formed of a very tough material, and kept open for a certain distance by hoops inserted in their walls. These hoops

gradually cease, but the tubes still pass on, getting smaller and smaller, until they finally end in the air sacs. One tube, and one only, enters each air sac. Within the air sacs are situated those countless little compartments all covered with capillaries which I spoke of as the air cells.

So much, then, regarding the structure of the lungs and the vessels which are distributed within them. Let us next turn to the chest, the hollow box in which the lungs and heart are deposited. The chest is supported behind by the back bone, which passes down from the neck like the keel of a ship. Twelve bones, known as the ribs, are hinged on to each side of the back bone. These bones enclose and protect the cavity of the chest. In front the ten upper ribs are more or less closely attached to a plate of bone, called the breast bone. In passing from the spine to the breast bone the ribs take a slanting direction, inclining somewhat downwards. When we open our chests, as we do in breathing, they alter their position, and instead of inclining downwards and forwards become nearly horizontal, pushing the breast bone forwards and a little upwards. By this movement the chest is made deeper. The distance from the spine to the breast bone being increased it becomes also wider, the two sides being separated by a greater distance. This is owing to the shape of the ribs. If you examine them they look like tightly strung bows. When the chest is at rest the curved face of these bows hangs as it were downwards; but when it expands this face is directed nearly straight outwards, and by reason of this rotation or turn of the ribs the interior of its cavity becomes wider. But not only does the chest gain in depth and in width but it gains also in length, and it gains in length because it has a moveable floor. This floor is known as the diaphragm. It is composed of bands of flesh knit together so as to form a thin partition curtain between the chest and the digestive organs. It is firmly attached to the ribs, the spine, and the breast bone. In breathing this partition is drawn downwards, and then the cavity of the chest is increased in length also. Thus you will observe that in breathing we enlarge our chests in every direction, from before backwards, from above downwards, and from side to side.

[Dr. Morgan illustrated the enlargement of the chest in width and in depth by means of a wooden contrivance, several cross bars being attached to an upright post. These bars inclined downwards, but as they were raised and became horizontal, it was readily seen that the distance between their free extremities and the part to which they were hinged was increased. As these bars

were curved and turned on their axes, they illustrated at the same time the increase of the chest in width.]

I will now ask you to look at this glass jar which I hold in my hand. It contains the lungs of a sheep. The windpipe which passes from the lungs is closely fitted into the neck of the jar: across its floor is spread a piece of India-rubber sheeting. You will observe that when I draw down the elastic floor of the jar the lungs which before hung empty are increased to three or four times their size. They are larger because they are now full of air which has rushed down the windpipe. Exactly the same thing takes place when we expand or open out our chests. They become larger, and as rapidly as they grow larger, so rapidly does the air pass down the windpipe and fill them out. And why does the air do so? Because, as we are told, nature abhors a vacuum: that is, nature will not allow any place to be altogether empty, and if it cannot fill it with anything else it fills it with air. If when we open out our chests air did not enter them there would be a vacuum within us. This, then, is what takes place when we breathe: air enters whether we will or not—we cannot shut it out. Try to hold your breath, and you will find that you cannot do so sufficiently long to do yourself any real harm. It is recorded that a man once tried to commit suicide by holding his breath, but he could not do it: he was able to hold his head under water till he drowned himself, but he could not by the force of his will shut out the air from his lungs. From what I have said you will perceive that when we speak of drawing in a long breath we do not express ourselves correctly—we speak as if we swallowed air as we swallow water; we do no such thing. By means of the muscles which are attached to the chest we open out its cavity, and then the air finds its own way in whether we will or no.

Let me now say one or two words in regard to the air or atmosphere which surrounds us. The air covers all this earth on which we live to a height of some fifty miles—hence it extends about that distance above our heads. In small quantities it is altogether invisible. In fact, you see objects through it as though it did not exist at all. In large volumes however, it has a blue colour—hence in looking up into the sky on a clear day it looks blue. It looks blue because there is a great quantity of air above us—so, too, the distant hills in fine weather look blue because a great mass of air lies between the hills and our eyes. Look at this jar of blue dye on the table. It is a rich deep blue; but when I fill this narrow glass tube with some of the coloured water in the jar you observe that it looks white like water. Just in the same

manner large quantities of air look blue, and small quantities have no colour at all. Let us next consider what the air is composed of. It is a mixture of two gases, oxygen and nitrogen, gases of which I have frequently spoken to you. If we separate these two gases we shall find that we have about 21 parts of oxygen and 79 parts of nitrogen. Oxygen is the active gas—the feeding and warming gas of which we make use when the two together enter our lungs, and nitrogen is the gas which is mixed with the oxygen lest it should be too strong for us and burn us away too fast. As experience has taught us to dilute our brandy, so has nature diluted for us the air. We can neither drink neat brandy with impunity nor breathe neat oxygen. Let us next follow the air into the lungs, and discover what takes place when it gets there. If we examine some air just as it is entering the chest, and again after it has been in contact with the lungs, we shall find that it has undergone a change. The air that comes out at the nostrils is not the same air as that which went in: and what is the change it has undergone? It has left behind it a considerable portion of the oxygen, and it has taken in exchange for the oxygen nearly the same quantity of carbonic acid gas. You will think, perhaps, that an exchange of two mere invisible gases cannot be a matter of any very great moment to us. It is, however, a matter of such moment that, should anything interpose to prevent it, within five minutes we would certainly die.

We will now follow the oxygen into the lungs and see what becomes of it. Every time we breathe or open out our chests nearly one pint of air passes down into the lungs. This pint contains about 40 tablespoonsful of air, 30 of nitrogen, and 10 of oxygen. The nitrogen we return to the air almost exactly as it entered, retaining but a fractional portion of it; of the oxygen, however, we keep about two tablespoonsful; and what becomes of this oxygen? It enters the capillary blood vessels. How does it enter them? It passes through their coats; oxygen passes *in* through their coats, and carbonic acid passes *out* through their coats, and takes the place of the oxygen, which is then withdrawn from the air. Thus there is exchange, but no robbery. But how, you may ask, can a gas pass through a tube—how can the oxygen get into the capillaries? What did I tell you about fluids in speaking of digestion? I told you that if fluids of a different weight are separated by a thin animal membrane, such as the coat of a capillary tube, the lighter fluid will pass out with great readiness, while at the same time the heavier fluid will pass in; in other words, an interchange will be set up between the contents of

the vessels and the tissues which surround them. The same thing takes place in the case of gases. When two gases are separated by a thin animal membrane, such as the coats of the capillaries of the lungs, they intermingle as though there was no intervening tube at all. Hence, while the carbonic acid in the tubes passes out the oxygen outside the tubes passes in; and what becomes of the oxygen when it does enter the capillaries? It is then stowed away in the red corpuscles of the blood. The red corpuscles which come to the lungs like so many little bottles of sodawater charged with carbonic acid, empty out their gas—a gas which proves depressing to the system, and in exchange for that lowering gas they take in another which endues them with renewed life and energy; they, as it were, discharge their sodawater and become filled with champagne. At the same time from being black and travel-stained they become red and bright. and cheerily travel on to the left side of the heart. Here they enter the left upper chamber by the four veins of the lungs; from the left upper they pass to the left lower, and are then pumped out into the great central artery of the body. By this artery they are distributed to every tissue and organ The brain is then stimulated by the invigorating stream which goes to supply it, and readily grapples with its work; the muscles feel springy and elastic, braced up for their labours. Thus we see that the oxygen enters the red corpuscles, stimulates them to action, and is then distributed by the arteries to the capillaries. So long as it remains in the arteries it is still, as it were, bottled up in the corpuscles, but on entering these little vessels it is subjected to a change. In the arteries the blood moves rapidly, travelling a distance of a foot in little more than in a second, but in the capillaries it slowly trails along at the rate of about an inch in a minute. Here, then, as the corpuscles tarry in their course, sluggishly dawdling along, the hungry tissues outside the capillaries rob them of their oxygen, the oxygen passing through the coats of the corpuscles and the tubing of the capillaries till it comes in contact with the carbon of the used up tissues. Immediately on coming in contact with this carbon chemical combination takes place; in other words, the two become united together; but in uniting both are changed, and then they are no longer called carbon and oxygen, but carbonic acid. Thus, in fact, at the capillaries oxygen takes carbon into partnership (a used up partner certainly), and then the firm under the name of "carbonic acid" returns to the corpuscles, takes up its abode within them, changes their colour from red to black, is floated by them

down the current of the veins, is emptied into the right upper chamber of the heart, is passed from the upper into the lower, is then forced out into the lungs, and is there once more exchanged for oxygen. Thus we have followed the oxygen from the lungs to the various tissues of the body, seen how it becomes united with carbon, how its influence for good on the system is destroyed through this union, and how, after being no longer of any use, it is cast out with the air at the lungs. If we examine the air which passes from the lungs we shall find that after having been breathed it receives from the blood about the same quantity of carbonic acid as the oxygen, which it appropriated to itself; about two tablespoonsful of oxygen are taken in, about two tablespoonsful of carbonic acid are given out. Let me now try to prove to you that air which has been breathed really contains a considerable quantity of carbonic acid. I have in this flask some lime water—lime dissolved in water. You will observe that it is at present quite clear. I now breathe into the lime water through this glass tube, and the water looks white and milky. Why does it do so? Because the carbonic acid of my breath has united with the lime dissolved through the water, forming what is called carbonate of lime, a substance which will not dissolve in water but remains suspended in it as a white precipitate. Had there been no carbonic acid in my breath this carbonate of lime would not have been formed. [Dr. Morgan then ignited a piece of charcoal and placed it under a jar of oxygen gas: the brilliant sparks caused this illustration to be much applauded.] You seem pleased with this experiment. Why have I shown it to you? I have shown it to you in order that you may see how eagerly oxygen and carbon unite together. The two rush, as it were, into each other's arms and become changed into carbonic acid. Look now at the jar: you will observe that no more sparks are given off: the charcoal has disappeared, while the invisible gas which has taken its place is formed out of it and the oxygen which surrounded it. Now this same union of oxygen and carbon takes place just outside the capillary vessels, the two combine, and, in combining, give out heat. The giving off of this heat is not accompanied by sparks, but is rather a sort of smouldering fire which is continually going on within us; and every time the corpuscles bring a fresh cargo of oxygen this fire is, as it were, fanned. If it is difficult for you to understand that two substances can unite together and give out warmth while yet there is no visible flame, look at this glass flask; it contains some oil of vitriol, I add water, and you see that steam is generated and rises out of the glass. Here, then, you

have heat disengaged by the union of two substances, and yet there is no flame. The same thing takes place in the warming of the body.

I told you just now that we do not express ourselves correctly when we speak of drawing in our breath. We are incorrect also when we make use of such an expression as "emptying the chest." We are incorrect because, do what we will, we cannot empty out all the air which our lungs contain. A man's lungs will hold between three and four quarts of air, but so far is he from changing the whole of this air every time he breathes, that he barely admits and gives out a single pint. Thus there is always present in the lungs a large reserve store of air, of which a comparatively small quantity is constantly being changed. When we take a long breath, or open our chests as wide as ever we can, then we admit about three pints of air; but even then there is at least an equal quantity left in the lungs which we have no power to force out. If you watch a person breathing you will find that he expands his chest about fifteen times in a minute. Every now and then, however, especially if the air be bad, such as we find it in theatres and concert rooms, we sigh or yawn—in other words, we take a deep breath. In such places the lungs seem to tell us, when they force us to yawn, that although they would be quite satisfied with a pint of pure country air, they must have occasionally at least an extra quart of the sort of stuff we there supply them with. Besides containing a large quantity of carbonic acid, air which has been breathed is also saturated with moisture. If you breathe into a glass jar for 24 hours you will find at the end of that time that the jar will contain about a pint of water. This water will first settle round the sides of the jar, as you see it on the glass windows of a cab or an omnibus, and will then flow in drops to the bottom of the vessel. This water all comes out of the lungs, being diffused through the air which has been breathed in the form of invisible vapour. If you allow the water which you have collected to stand for a few days, you will find that it will not keep, but will putrify and become offensive. Thus you will perceive that when a large number of persons are collected together in a small and close room they are continually admitting into their lungs air which has been not only deprived of a considerable portion of its oxygen but is vitiated by the admixture of carbonic acid gas and impure water. Air which has been once breathed contains about five per cent of carbonic acid. Such air would very soon prove fatal to even the strongest man; indeed, one per cent of this gas is a larger proportion than any of us could endure for a length of time. [Dr. Morgan, with

a view of showing the effects of vitiated air, placed a live pigeon in a jar, into which he admitted carbonic acid. In a short time the pigeon, which had before been well and lively, began to hang its head, gasp, and look very uncomfortable : as soon as fresh air was admitted, the pigeon immediately revived.] Dr. Morgan continued, I have been giving this pigeon a dose of what you are continually giving yourselves when you close up your windows and doors, and stuff a sack into the chimney. It is very fortunate for you that in spite of all your efforts to keep out fresh air you cannot altogether succeed in doing so. The air will rush in, and will not permit you to destroy yourselves. If, however, one of you were placed under a large glass jar, into which it would be impossible for the outer air to enter, and where you would be forced to re-admit into your lungs an unchanged atmosphere, you would be effectually suffocated in the course of a few hours. There are numerous instances on record of large numbers of human beings perishing for want of fresh air. In the year 1757, 146 persons were locked up for the night in a room in Calcutta, which was only 18 feet square. The next morning only 23 of the number were left alive. The rest perished after enduring intense sufferings. You have all heard of this room, which, from the terrible tragedy enacted within its walls, obtained the name of the Black Hole of Calcutta. A similar accident occurred more lately, on the 2nd of December, 1848, when the steamer Londonderry sailed from Sligo to Liverpool, with 200 emigrants on board. A gale of wind came on, and the captain ordered the passengers below. They were packed together in a small cabin. Not content with fastening down the hatches he covered them with tarpaulin. The agony endured by these unfortunate people in this dungeon was frightful, and so tightly were they imprisoned that 73 of the 200 perished before their pitiable condition was discovered. These persons died from suffocation; the air which surrounded them was so charged with carbonic acid that the black venous blood which entered their lungs could not obtain its supply of oxygen, and consequently could not be purified. It was therefore passed on to the left side of the heart comparatively unchanged. But these chambers knew that it was an intruder; they knew that as the right side of the heart receives and distributes the sewage blood so does the left receive and dispense the pure blood. When these chambers therefore are entered by the black blood an intense sense of oppression seems to weigh upon the chest. This is a feeling which, in its milder forms, we have all experienced in holding our heads under water. The oppression of the chest is succeeded by dizziness of the head. This dizziness arises when

the black blood is forced from the heart into the delicate tissues of the brain. At the same time strange sensations invade the limbs, attended by those agonizing sufferings which are experienced in the early stages of drowning; for remember that the death which attends on drowning is a death from suffocation. The interchange between carbonic acid and oxygen cannot go on at the lungs, black blood is distributed through the system, and then all is confusion till the flickering flame of life finally expires.

Having spoken to you at some length on the great danger of bad air let me advise you always to try as much as possible to attend to what is called the ventilation of your rooms—that is, to keeping the air within your dwellings tolerably fresh. I believe nothing contributes in a greater degree to deteriorate the inhabitants of our large towns than the bad air by which they are surrounded. I am well aware that it is difficult in winter to open the windows in a small room—you cannot avoid getting between the window and the fire, and are then exposed to a draught. It is possible, however, to admit air without exposing ourselves to cold draught. I here show you a model of a ventilator which I have had introduced at the Salford hospital. A little box about an inch and a half in depth is fixed into the upper part of each window, and extends for some six inches down the sash. The outer facing of this box is made of perforated zinc. Into this box is fitted another box which can be removed from the sash and taken down. The side of this box which looks into the room is covered with fine gauze wire; it is filled with finely carded cotton wool and is then fitted into the sash. The outer air then gains admission into the room by passing through the zinc, the wool, and the gauze wire. In this manner, while the wool is perfectly pervious to the air, blacks are filtered out, moisture is absorbed, and the force of currents of air is as it were broken. At the same time the air is to some extent warmed by the mechanical friction to which it is exposed in passing through the ventilator. The cotton wool requires to be changed every five or six months. It is then found loaded with blacks, which would otherwise have made their way into the room. This contrivance has been in use at the Salford hospital for about two years, and has kept the air of the wards perfectly fresh, whilst even during the late severe weather the patients have not complained of draughts. Some such contrivance you might arrange for yourselves.

This, my friends, is the last lecture which I have arranged to give you at present. From what I have told you, you will, I hope, have learned something which may prove useful to you: enough

perhaps to induce you to study some simple little books of physiology for yourselves. The diagrams and the experiments which I have shown you would assist you in understanding much which would otherwise have been unintelligible to you. I have endeavoured to the utmost of my power to express myself in the simplest language. I fear some of you who know something of physiology will have thought me childishly simple. These lectures, however, were not intended for those who already knew something of the sciences about which they have treated, but for those who knew nothing at all about them. It is to this latter class of my audience that I have addressed myself, and if I have succeeded in interesting them I am quite satisfied. For one thing, however, I must thank you all, and that is for the marked attention with which you have listened to me. In looking at your faces I have not observed a single yawn. Everywhere my eyes have lighted upon thoughtful and intelligent countenances. For this attention, which has so much assisted me in speaking to you, I beg most heartily to thank you.

CORAL AND CORAL REEFS.

A LECTURE

BY

PROFESSOR HUXLEY, LL.D., F.R.S.,

Delivered in the Hulme Town Hall, Manchester, November 4, 1870.

THE subject upon which I wish to address you to-night is the structure and origin of Coral and Coral Reefs. Under the head of "coral" there are included two very different things; one of them is that substance which I imagine a great number of us have champed when we were very much younger than we are now,—the common red coral, which is used so much, as you know, for the edification and the delectation of children of tender years, and is also employed for the purposes of ornament for those who are much older, and as some think might know better. The other kind of coral is a very different substance; it may for distinction sake be called the white coral; it is a material which most assuredly not the hardest-hearted of baby farmers would give to a baby to chew, and it is a substance which is to be seen only in the cabinets of curious persons, or in museums, or, may be, over the mantel-pieces of seafaring men. But although the red coral, as I have mentioned to you, has access to the very best society; and although the white coral is comparatively a despised product, yet in this, as in many other cases, the humbler thing is in reality the greater; the amount of work which is done in the world by the white coral being absolutely infinite compared with that effected by its delicate and pampered namesake. Each of these substances, the white coral and the red, however, has a relationship to the other. They are, in a zoological sense, cousins, each of them being formed by the same

kind of animals in what is substantially the same way. Each of these bodies is, in fact, the hard skeleton of a very curious and a very simple animal, more comparable to the bones of such animals as ourselves than to the shells of oysters or creatures of that kind; for it is the hardening of the internal tissue of the creature, of its internal substance, by the deposit in the body of a material which is exceedingly common, not only in fresh but in sea water, and which is especially abundant in those waters which we know as "hard," those waters, for example, which leave a "fur" upon the bottom of a tea-kettle. This "fur" is carbonate of lime, the same sort of substance as limestone and chalk. That material is contained in solution in sea water, and it is out of the sea water in which these coral creatures live that they get the lime which is needed for the forming of their hard skeleton.

But now what manner of creatures are these which form these hard skeletons? I dare say that in these days of keeping aquaria, of locomotion to the sea-side, most of those whom I am addressing may have seen one of those creatures which used to be known as the "sea anemone," receiving that name on account of its general resemblance, in a rough sort of way, to the flower which is known as the "anemone;" but being a thing which lives in the sea, it was qualified as the "sea anemone." It is very much such a creature as you may see in those diagrams; but, perhaps, I may make it more plain to you by sketching it upon this black board. Well, then, you must suppose a body shaped like a short cylinder, the top cut off, and in the top a hole rather oval than round. All round this aperture, which is the mouth, imagine that there are placed a number of feelers forming a circle. The cavity of the mouth leads into a sort of stomach, which is very unlike those of the higher animals, in the circumstance that it opens at the lower end into a cavity of the body, and all the digested matter, converted into nourishment, is thus distributed through the rest of the body. That is the general structure of one of these sea anemones. If you touch it it contracts immediately into a heap. It looks at first quite like a flower in the sea, but if you touch it you find that it exhibits all the peculiarities of a living animal; and if anything which can serve as its prey comes near its tentacles, it closes them round it and sucks the material into its stomach and there digests it and turns it to the account of its own body.

These creatures are very voracious, and not at all particular what they seize; and sometimes it may be that they lay hold of a shellfish which is far too big to be packed into that interior cavity, and, of course, in any ordinary animal a proceeding

of this kind would give rise to a very severe fit of indigestion. But this is by no means the case in the sea anemone, because when digestive difficulties of this kind arise he gets out of them by splitting himself in two; and then each half builds itself up into a fresh creature, and you have two polypes where there was previously one, and the bone which stuck in the way lying between them! Not only can these creatures multiply in this fashion, but they can multiply by buds. A bud will grow out of the side of the body (I am not speaking of the common sea anemone, but of allied creatures) just like the bud of a plant, and that will fashion itself into a creature like the parent. There are some of them in which these buds remain connected together, and you will soon see what would be the result of that. If I make a bud grow out here, and another on the opposite side, and each fashions itself into a new polype, the practical effect will be that before long you will see a single polype converted into a sort of tree or bush of polypes. And these will all remain associated together, like a kind of co-operative store, which is a thing I believe you understand very well here,—each mouth will help to feed the body and each part of the body help to support the multifarious mouths. I think that is as good an example of a zoological co-operative store as you can well have. Such are these wonderful creatures. But they are capable not only of multiplying in this way, but in other ways, by having a more ordinary and regular kind of offspring. Little eggs are produced in the bodies of these creatures, and those eggs are hatched and the young are passed out by the way of the mouth, and they go swimming about as little oval bodies covered with a very curious kind of hairlike processes. Each of these processes is capable of striking the water like an oar; and the consequence is that the young creature is propelled through the water. So that you have the young polype floating about in this fashion, covered by its vibratile cilia, as these long filaments, which are capable of vibration, are termed. And thus although the polype itself may be a fixed creature unable to move about, it is able to spread its offspring over great areas. For these creatures not only propel themselves, but while swimming about in the sea for many hours, or perhaps days, it will be obvious that they must be carried hither and thither by the currents of the sea, which not unfrequently move at the rate of one or two miles an hour. Thus, in the course of a few days, the offspring of this stationary creature may be carried to a very great distance from its parent; and having been so carried it loses these organs by which it is propelled, and settles down upon the bottom of the sea and grows up again into the form and condition

of its parent. So that if you suppose a single polype of this kind settled upon the bottom of the sea, it may by these various methods—that is to say, by cutting itself in two, which we call "fission;" or by budding; or by sending out these swimming embryos,—multiply itself to an enormous extent, and give rise to thousands, or millions, of progeny in a comparatively short time; and these thousands, or millions, of progeny may cover a very large surface of the sea bottom; in fact, you will readily perceive that, give them time, and there is no limit to the surface which they may cover.

Having understood thus far the general nature of these polypes, which are the fabricators both of the red and white coral, let us consider a little more particularly how the skeletons of the red coral and of the white coral are formed. In that right hand diagram, the one brilliantly coloured, you have a picture of the living animal which forms the red coral. Perhaps I may make it more intelligible by a sketch upon the black board. The red coral polype perches upon the sea bottom, it then grows up into a sort of stem, and out of that stem there grow branches, each of which has its own polypes; and thus you have a kind of tree formed, every branch of the tree terminated by its polype. It is a tree, but at the end of the branches there are open mouths of polypes instead of flowers. Thus there is a common soft body connecting the whole, and as it grows up the soft body deposits in its interior a quantity of carbonate of lime, which acquires a beautiful red or flesh colour, and forms a kind of stem running through the whole, and it is that stem which is the red coral. The red coral grows principally at the bottom of the Mediterranean Sea, at very great depths, and the coral fishers, who are very adventurous seamen, take their drag nets, of a peculiar kind, roughly made, but efficient for their purpose, and drag them along the bottom of the sea to catch the branches of the red coral, which become entangled, and are thus brought up to the surface. They are then allowed to putrify, in order to get rid of the animal matter, and the red coral is the skeleton that is left.

In the case of the white coral, the skeleton is more complete. In the red coral, the skeleton belongs to the whole: in the white coral there is a special skeleton for every one of these polypes in addition to that for the whole body. I will make a sketch to illustrate it. There is a skeleton formed in the body of each of them, like a cup, divided by a number of radiating partitions towards the outside; and that cup is formed of carbonate of lime, only not stained red, as in the case of the red coral. And all these cups are joined together into a common

branch, the result of which is the formation of such a beautiful coral tree as you see here, which I am enabled to show by the kindness of the curator of the museum of the Natural History Society. This is a great mass of madrepore, and in the living state every one of the ends of these branches was terminated by a beautiful little polype, like a sea anemone, just as you see at the end of those branches in the diagram; and all the skeleton was covered by a soft body which united the polypes together. You must understand that all this skeleton has been formed in the interior of the body, to suit the branched body of the polype mass, and that it is as much its skeleton as our own bones are our skeleton. In this next coral the creature which has formed the skeleton has divided itself as it grew, and consequently has formed a great expansion; but scattered all over this surface there were polype bodies like those I previously described. Again, when this great cup was alive, the whole surface was covered with a beautiful body upon which were set innumerable small polype flowers, if we may so call them, often brilliantly coloured; and the whole cup was built up in the same fashion by the deposit of carbonate of lime in the interior of the combined polype body, formed by budding and by fission in the way I described. You will perceive that there is no necessary limit to this process. There is no reason why we should not have coral three or four times as big; and there are certain creatures of this kind that do fabricate very large masses, twice as big as this table, or half spheres several feet in diameter. Thus the activity of these animals in separating carbonate of lime from the sea and building it up into definite shapes is very considerable indeed.

Now I think I have said sufficient—as much as I can without taking you into technical details, of the general nature of these creatures which form coral. The animals which form coral are scattered over the seas of all countries in the world. The red coral is comparatively limited, but the polypes which form the white coral are widely scattered. There are some of them which remain single, or which give rise to only small accumulations and the skeletons of these, as they die, accumulate upon the bottom of the sea, but they do not come to much; they are washed about and no not adhere together, but become mixed up with the mud of the sea. But there are certain parts of the world in which the coral polypes which live and grow are of a kind which remain, adhere together, and form great masses. They differ from the ordinary polypes just in the same way as those

plants which form a peat-bog or meadow-turf differ from ordinary plants. They have a habit of growing together in masses in the same place; they are what we call "gregarious" things; and the consequence of this is, that as they die and leave their skeletons, those skeletons form a considerable solid aggregation at the bottom of the sea, and other polypes perch upon them, and begin building upon them, and so by degrees a great mass is formed. And just as we know there are some ancient cities in which you have a British city, and over that the foundations of a Roman city; and over that a Saxon city, and over that again a modern city, so, in these localities of which I am speaking, you have the accumulations of the foundations of the houses, if I may use the term, of nation after nation of these coral polypes; and these accumulations may cover a very considerable space, and may rise in the course of time from the bottom to the surface of the sea.

Mariners have a name which they apply to all sorts of obstacles consisting of hard and rocky matter which comes in their way in the course of their navigation; they call such obstacles "reefs," and they have long been in the habit of calling the particular kind of reef, which is formed by the accumulation of the skeletons of dead corals, by the name of "coral reefs;" therefore, those parts of the world in which these accumulations occur have been termed by them "coral reef areas," or regions in which coral reefs are found. There is a very notable example of a simple coral reef about the island of Mauritius, which I dare say you all know, lies in the middle of the Indian Ocean. It is a very considerable and beautiful island, and is surrounded on all sides by a mass of coral, which has been formed in the way I have described; so that if you could get upon the top of one of the peaks of the island, and look down upon the Indian Ocean, you would see that the beach round the Island was continued outward by a kind of shallow terrace, which is covered by the sea, and where the sea is quite shallow; and at a distance, varying from three-quarters of a mile to a mile and a half from the proper beach, you would see a line of foam, or surf, which looks most beautiful in contrast with the bright green water in the inside, and the deep blue of the sea beyond. That line of surf indicates the point at which the waters of the ocean are breaking upon the coral reef which surrounds the island. You see it sweep round the island upon all sides, except where a river may chance to come down, and that always makes a gap in the shore.

There are two or three points which I wish to bring clearly before your notice about such a reef as this. In the first place, you

perceive it forms a kind of fringe round the island, and is therefore called a "fringing reef." In the next place, if you go out in a boat, and take soundings at the edge of the reef, you find that the depth of the water is not more than from 20 to 25 fathoms—that is about 120 to 150 feet. Outside that point you come to the natural sea bottom; but all inside that depth is coral, built up from the bottom by the accumulation of the skeletons of innumerable generations of coral polypes. So that you see the coral forms a very considerable rampart round the island. What the exact circumference may be I do not remember, but it cannot be less than 100 miles, and the outward height of this wall of coral rock nowhere amounts to less than about 100 or 150 feet.

When the outward face of the reef is examined, you find that the upper edge, which is exposed to the wash of the sea, and all the seaward face, is covered with those living plant-like flowers which I have described to you. They are the coral polypes which grow, flourish, and add to the mass of calcareous matter which already forms the reef. But towards the lower part of the reef, at a depth of about 120 feet, these creatures are less active, and fewer of them at work; and at greater depths than that you find no living coral polype at all; and it may be laid down as a rule, derived from very extensive observation, that these reef-building corals cannot live in a greater depth of water than about 120 to 150 feet. I beg you to recollect that fact, because it is one I shall have to come back to by and by, and to show to what very curious consequences that rule leads. Well then, coming back to the margin of the reef, you find that part of it which lies just within the surf to be coated by a very curious plant, a sort of sea weed, which contains in its substance a very great deal of carbonate of lime, and looks almost like rock; this is what is called the nullipore. More towards the land, we come to the shallow water upon the inside of the reef, which has a particular name, derived from the Spanish or Portuguese—it is called a "lagoon" or lake. In this lagoon there is comparatively little living coral; the bottom of it is formed of coral mud. If we pounded this coral in water, it would be converted into calcareous mud, and the waves during storms do for the coral skeletons exactly what we might do for this coral in a mortar; the waves tear off great fragments and crush them with prodigious force, until they are ground into the merest powder, and that powder is washed into the interior of the lagoon, and forms a muddy coating at the bottom. Beside that, there are a great many animals that prey upon the coral—fishes, worms, and creatures of that kind, and all these, by

their digestive processes, reduce the coral to the same state, and contribute a very important element to this fine mud. The living coral found in the lagoon, is not the reef building coral; it does not give rise to the same massive skeletons. As you go in a boat over these shallow pools, you see these beautiful things, coloured red, blue, green, and all colours, building their houses; but these are mere tenements, and not to be compared in magnitude and importance to the masses which are built by the reef-builders themselves. Now, such a structure as this is what is termed a "fringing reef" You meet with fringing reefs of this kind not only in the Mauritius, but in a number of other parts of the world. If these were the only reefs to be seen anywhere, the problem of the formation of coral reefs would never have been a difficult one. Nothing can be easier than to understand how there must have been a time when the coral polypes came and settled on the shores of this island, everywhere within the 20 to 25 fathom line, and how, having perched there, they gradually grew until they built up the reef.

But these are by no means the only sort of coral reefs in the world; on the contrary, there are very large areas, not only of the Indian Ocean, but of the Pacific, in which many many thousands of square miles are covered either with a peculiar kind of reef, which is called the "encircling reef," or by a still more curious reef which goes by the name of the "atoll." There is here a very good picture, which Professor Roscoe has been kind enough to prepare for me, of one of these atolls, which will enable you to form a notion of it as a landscape. That is an exceedingly faithful illustration of the structure of an atoll. You have in the foreground of the picture the waters of the Pacific. You must fancy yourself in the middle of the great Ocean, and you perceive that there is an almost circular island, with a low beach, which is formed entirely of coral sand; growing upon that beach you have vegetation, which takes, of course, the shape of the circular land; and then, in the interior of the circle, there is a pool of water, which is not very deep—probably in this case not more than eight or nine fathoms—and which forms a strange and beautiful contrast to the deep blue water outside. This circular island, or atoll, with a lagoon in the middle, is not a complete circle; upon one side of it there is a break, exactly like the entrance into a dock; and, as a matter of course, these circular islets, or atolls, form most efficient breakwaters, for if you can only get inside your ship is in perfect safety, with admirable anchorage in the interior. If the ship were lying within a mile of that beach, the water would be

one or two thousand feet deep; therefore, a section of that atoll, with the soundings as deep as this all round, would give you the notion of a great cone, cut off at the top, and with a shallow cup in the middle of it. Now, what a very singular fact this is, that we should have rising from the bottom of the deep ocean a great pyramid, beside which all human pyramids sink into the most utter insignificance! These singular coral limestone structures are very beautiful, especially when crowned with cocoa-nut trees. The beauty is better shown in the coloured diagram, which we will now throw upon the screen. There you see the long line of land, covered with vegetation—cocoa-nut trees—and you have the sea upon the inner and outer sides, with a vessel very comfortably riding at anchor; though I must say, as an old sea-faring person, that the breakers are rather nearer the ship than I should like to see them if I were on board. That is one of the remarkable forms of reef in the Pacific. Another is a sort of half-way house, between the atoll and the fringing reef; it is what is called an "encircling reef." In this case you see an island rising out of the sea, and at two or three miles distance, or more, and separated by a deep channel, which may be eight to twelve fathoms deep, there is a reef, which encircles it like a great girdle; and outside that again the water is one or two thousand feet deep. I spent three or four years of my life in cruising about a modification of one of these encircling reefs, called a "barrier reef," upon the east coast of Australia—one of the most wonderful accumulations of coral rock in the world. It is about 1,100 miles long, and varies in width from one or two to many miles. It is separated from the coast of Australia by a channel of about twenty-five fathoms depth; while outside, looking toward America, the water is two or three thousand feet deep at a mile from the edge of the reef. This is an accumulation of limestone rock, built up by corals, to which we have no parallel anywhere else. Imagine to yourself a heap of this material more than one thousand miles long, and several miles wide. That is a barrier reef; but a barrier reef is merely as it were a fragment of an encircling reef running parallel with the coast of a great continent.

I told you that the polypes which built these reefs were not able to live at a greater depth than 20 to 25 fathoms of water; and that is the reason why the fringing reef goes no farther from the land than it does. And for the same reason, if the Pacific could be laid bare we should have a most singular spectacle. There would be a number of mountains with truncated tops scattered over it, and those mountains would have an appearance just the very

reverse of that presented by the mountains we see on shore. You know that the mountains on shore are covered with vegetation at their bases, while their tops are barren or covered with snow; but these mountains would be perfectly bare at their bases, and all round their tops they would be covered with a beautiful vegetation of coral polypes. And not only would this be the case, but we should find that for a considerable distance down, all the material of these atoll and encircling reefs was built up of precisely the same coral rock as the fringing reef. That is to say, you have an enormous mass of coral rock at a depth below the surface of the water where we know perfectly well that the coral animals could not have lived to form it. When those two facts were first put together, naturalists were quite as much puzzled as I dare say you are, at present, to understand how these two seeming contradictions could be reconciled; and all sorts of odd hypotheses were resorted to. It was supposed that the coral did not extend so far down, but that there was a great chain of submarine mountains stretching through the Pacific, and that the coral had grown upon them. But only fancy what a supposition that was, for you would have to imagine that there was a chain of mountains a thousand miles or more long, and that the top of every mountain came within 20 fathoms of the surface of the sea, and neither rose above nor sunk beneath that level. That is highly improbable: such a chain of mountains was never known. Then how can you possibly account for the curious circular form of the atolls by any supposition of this kind? I believe there was some one who imagined that all these mountains were volcanoes, and that the reefs had grown round the tops of the craters! So we all stuck fast. I may say "we," though it was rather before my time. And when we all stick fast, it is just the use of a man of genius that he comes and shows us the meaning of the thing. He generally gives an explanation which is so ridiculously simple that everybody is ashamed he did not find it out before; and the way such a discoverer is often rewarded is by finding out that some one had made the discovery before him! I do not mean to say that it was so in this particular instance, because the great man who played the part of Columbus and the egg on this occasion has, I believe, always had the full credit which he so well deserves. The discoverer of the key to these problems was a man whose name you know very well in connection with other matters, and I should not wonder if some of you have heard it said that he was a superficial kind of person who did not know much about the subject on which he writes. He

was Mr. Darwin, and this brilliant discovery of his was made public thirty years ago, long before he became the celebrated man he now is; and it was one of the most singular instances of that astonishing sagacity which he possesses of drawing consequences by way of deduction from simple principles of natural science—a power which has served him in good stead on other occasions. Well, Mr. Darwin, looking at these curious difficulties, and having that sort of knowledge of natural phenomena in general, without which he could not have made a step towards the solution of the problem, said to himself—"It is perfectly clear that the coral which forms the base of the atolls and fringing reefs could not possibly have been formed there if the level of the sea has always been exactly where it is now, for we know for certain that these polypes cannot build at a greater depth than 20 to 25 fathoms, and here we find them at 50 or 100 fathoms."

That was the first point to make clear. The second point to deal with was—if the polypes cannot have built there while the level of the sea has remained stationary, then one of two things must have happened—either the sea has gone up, or the land has gone down.

There is no escape from one of those two alternatives. Now the objections to the notion of the sea having gone up are very considerable indeed; for you will readily perceive that the sea could not possibly have risen a thousand feet in the Pacific without rising pretty much the same distance everywhere else; and if it had risen that height everywhere else since the reefs began to be formed, the geography of the world in general must have been very different indeed, at that time, from what it is now. And we have very good means of knowing that any such rise as this certainly has not taken place in the level of the sea since the time that the corals have been building their houses. And so the only other alternative was to suppose that the land had gone down, and at so slow a rate that the corals were able to grow upward as fast as it went downward. You will see at once that this is the solution of the mystery, and nothing can be simpler or more obvious when you come to think about it. Suppose we start with a coral sea and put in the middle of it an island such as the Mauritius. Now let the coral polypes come and perch on the shore and build a fringing reef, which will stop when they come to 20 or 25 fathoms, and you will have a fringing reef like that round the island in the illustration. So long as the land remains stationary, so long as it does not descend so long will that reef be unable to get any further out, because the moment

the polype embryos try to get below they die. But now suppose that the land sinks very gradually indeed. Let it subside by slow degrees, until the mountain peak, which we have in the middle of it, alone projects beyond the sea level. The fringing reef would be carried down also; but we suppose that the sinking is so slow that the coral polypes are able to grow up as fast as the land is carried down; consequently they will add layer upon layer until they form a deep cup, because the inner part of the reef grows much more slowly than the outer part. Thus you have the reef forming a bed thicker upon the flanks of the island; but the edge of the reef will be very much further out from the land, and the lagoon will be many times deeper—in short, your fringing reef will be converted into an encircling reef. And if, instead of this being an island, it were a great continent like Australia, then you will have the phenomenon of a barrier reef which I have described. The barrier reef of Australia was originally a fringing reef. The land has gone slowly down; the consequence is the lagoon has deepened until its depth is now 25 fathoms, and the corals have grown up at the outer edge until you have that prodigious accumulation which forms the barrier reef at present. Now let this process go on further still; let us take the land a further step down, so as to submerge even the peak. The coral, still growing up, will cover the surface of the land, and you will have an atoll reef; that is to say, a more or less circular or oval ring of coral rock with a lagoon in the middle. Thus you see that every peculiarity and phenomena of these different forms of coral reef was explained at once by the simplest of all possible suppositions, namely, by supposing that the land has gone down at a rate not greater than that at which the coral polypes have grown up. You explain a Fringing Reef as a reef which is formed round land comparatively stationary; an Encircling Reef as one which is formed round land going down; and an Atoll as a reef formed upon land gone down; and the thing is so simple that a child may understand it when it is once explained.

But this would by no means satisfy the conditions of a scientific hypothesis. No man who is cautious would dream of trusting to an explanation of this kind simply because it explained one particular set of facts. Before you can possibly be safe in dealing with Nature—who is very properly made of the feminine gender, on account of the astonishing tricks which she plays upon her admirers!—I say before you can be safe in dealing with Nature—you must get two or three kinds of cross proofs, so as to make sure not only that your hypothesis fits that particular set of facts,

but that it is not contradicted by some other set of facts which is just as clear and certain. And it so happens, that in this case Mr. Darwin supplied the cross proofs as well as the immediate evidence. You have all heard of volcanoes, those wonderful vents in the surface of the earth out of which pour masses of lava, cinders and ashes, and the like. Now, it is a matter of observation and experience that all volcanoes are placed in areas in which the surface of the earth is undergoing elevation, or at any rate is stationary; they are not placed in parts of the world in which the level of the land is becoming lowered. They are all indications of a great subterranean activity, of a something being pushed up, and therefore naturally the land either gives way and lets it come through, or else is raised up by its violence. And so Mr. Darwin, being desirous not to merely put out a flashy hypothesis, but to get at the truth of the matter, said to himself, "If my notion of this matter is right, then atolls and encircling reefs, inasmuch as they are dependent upon subsidence, ought not to be found in company with volcanoes; and, *vice versa*, volcanoes ought not to be found in company with atolls, but they ought to be found in company with fringing reefs. And if you turn to Mr. Darwin's great work upon the coral reefs, you will see a very beautiful chart of the world, which he prepared with great pains and labour, showing the distribution on the one hand of the reefs, and on the other of the volcanoes; and you will find that in no case does the atoll accompany the volcano, or the volcano burst up among the atolls. It is most instructive to look at the great area of the Pacific on the map; and see the great masses of atolls forming in one region of it a most enormous belt, running from north-west to south-east; while the volcanoes, which are very numerous in that region, go round the margin, so that we can picture the Pacific to ourselves a section of a kind of very shallow basin—shallow in proportion to its width, with the atolls rising from the bottom of it, and at the margins the volcanoes. It is exactly as if you had taken a flat mass and lifted up the edges of it; the subterranean force which lifted up the edges shows itself in volcanoes, and as the edges have been raised, the middle part of the mass has gone down. In other words, the facts of physical geography precisely and exactly correspond with the hypothesis which accounts for the infinite varieties of coral reefs.

One other point, before I conclude, about this matter, for I find that time is running on very fast. These reefs, as you have just perceived, are in a most singular and unexpected manner indications of physical changes, of elevations and depressions

going on upon the surface of the globe. I dare say it may have surprised you to hear me talk in this familiar sort of way of land going up and down; but it is one of the universal lessons of geology that the land is going down and going up, and has been going up and down, in all sorts of places and to all sorts of distances, through all recorded time. Geologists would be quite right in maintaining the seeming paradox that the stable thing in the world is the fluid sea and the shifting thing is the solid land. That may sound a very hard saying at first, but the more you look into geology, the more you will see ground for believing that it is not a mere paradox.

In an unexpected manner, again, these reefs afford us not only an indication of change of place, but they afford an indication of lapse of time. The reef is a timekeeper of a very curious character; and you can easily understand why. The coral polype, like everything else, takes a certain time to grow to its full size; it does not do it in a minute; just as a child takes a certain time to grow into a man, so does the embryo polype take time to grow into a perfect polype and form its skeleton. Consequently every particle of coral limestone is an expression of time. It must have taken a certain time to separate the lime from the sea water. It is not possible to arrive at an accurate computation of the time it must have taken to form these coral islands, because we lack the necessary data; but we can form a rough calculation, which leads to very curious and striking results. The computations of the rate at which corals grow are so exceedingly variable, that we must allow the widest possible margin for error; and it is better in this case to make the allowance upon the side of excess. I think that anybody who knows anything about the matter will tell you that I am making a computation far in excess of what is probable, if I say that an inch of coral limestone may be added to one of these reefs in the course of a year. I think most naturalists would be inclined to laugh at me for making such an assumption, and would put the growth at certainly not more than half that amount. But supposing it to be so, what a very curious notion of the antiquity of some of these great living pyramids comes out by a very simple calculation. There is no doubt whatever that the sea faces of some of them are fully a thousand feet high, and if you take the reckoning of an inch a year, that will give you 12,000 years for the age of that particular pyramid or cone of coral limestone: 12,000 long years have these creatures been labouring in conditions which must have been substantially the same as they are now, otherwise the polypes could not have continued their work. But I believe I

very much understate both the height of some of these masses, and overstate the amount which these animals can form in the course of a year; so that you might very safely double this period as the time during which the Pacific Ocean, the general state of the climate, and the sea, and the temperature has been substantially what it is now; and yet that state of things which now obtains in the Pacific Ocean is the yesterday of the history of the life of the globe. Those pyramids of coral rock are built upon a foundation, which is itself formed by the deposits which the geologist has to deal with. If we go back in time and search through the series of the rocks, we find at every age of the world's history which has yet been examined, accumulations of limestone, many of which have certainly been built up in just the same way as those coral reefs which are now forming the bottom of the Pacific Ocean. And even if we turn to the oldest periods of geologic history, although the nature of the materials is changed; although we cannot apply to them the same reasonings that we can to the existing corals, yet still there are vast masses of limestone formed of nothing else than the accumulations of the skeletons of similar animals, and testifying that even in those remote periods of the world's history, as now, the order of things implies that the earth had already endured for a period of which our ordinary standards of chronology give us not the slighest conception. In other words, the history of these coral reefs, traced out honestly and carefully, and with the same sort of reasoning that you would use in the ordinary affairs of life, testifies, like every fact that I know of, to the prodigious antiquity of the earth since it existed in a condition in the main similar to that in which it now is.

SPECTRUM ANALYSIS.

A LECTURE

BY

PROFESSOR ROSCOE, F.R.S.,

Delivered in the Hulme Town Hall, Manchester, Nov. 9, 1870.

Whilst we all look with admiration at the countless stars which on a clear night, are seen to be brightly shining, or delight in the blaze of the midsummer sun, there are, perhaps, few amongst us who know that the light of the twinkling stars and that of the bright sun carries along with it some secrets of its nature which it has been the privilege of modern science to unfold. No less strange than true is it that by means of this light we are able to tell something about the composition of these heavenly bodies—we can learn what they are made of. Yet this seems almost incredible—that we should be able to tell what exists in the sun at a distance of ninety-one millions of miles; or still more, that we can say that substances which we know well on this earth, such as iron, sodium, magnesium, calcium, and hydrogen, are present in stars at distances from us so great, that the mind utterly fails to conceive of them, for though light travels at the rate of 192,000 miles per second, it may take 1,000 years for the light of some of these stars to reach earth.

I wish to explain to you, as clearly as I can, and using as plain language as may be, how these discoveries have been made, and to show you that this strange discovery is the result of plain and straightforward reasoning upon simple and exact observation and experiment. In endeavouring to do this I shall be very much aided by the fact which I am able to announce, that the continuation of this subject will be taken up next week by a gentleman who has rendered his name illustrious in connection with spectrum

analysis — Dr. Huggins — who will tell you, next Tuesday, how he has been able to discover the composition of the stars, though they are at such an inconceivable distance.

I shall confine myself to-night to the simpler and introductory portion of the subject, and endeavour to show you the principles upon which this language of the stars has been translated for us, by applying the discoveries in spectrum analysis in the first instance to the earth, and at the close of the lecture to the sun.

In the first place, I must remind you that it is the aim of the study of chemistry to determine of what the earth is made up; and I shall have to show you that spectrum analysis has taught us a great deal concerning the composition of our earth with which we were not formerly acquainted. Chemists have to ascertain the composition of everything that comes within their reach, whether that thing be fetched from the deepest mine, or from the highest point to which man has ascended, even in a balloon, or whether it comes from the north or south pole, or from the tropics. Chemists have discovered that substances can be divided into two great classes—those which have been divided into something different, and those which have not been so divided. The last of these are termed elementary bodies. We are acquainted with sixty-three of these elementary substances, and it is these that make up the substance of our earth, and therefore constitute the fabric of which the science of chemistry is composed. I need hardly remind you that because a body is invisible there is no reason to suppose that it does not exist. For instance, you know that coal gas is invisible, for if you open a gas tap you do not see anything come out; but if you put your nose to it you will perceive the smell of the gas. So that invisibility is no proof of the sameness of chemical bodies. We have a host of invisible bodies besides air and coal gas. Chemists, by their investigation of nature and her products, have discovered that all bodies can exist in three distinct states, namely, as solids, liquids, and gases. For instances as solid ice, liquid water, and gaseous steam. All substance, may be converted into gases, liquids, or solids, by adding or removing heat. We add heat to solid ice to convert it into water; we add heat to liquid water to make it into gaseous steam; and if we add heat enough to iron we can turn it into vapour. There is no substance which cannot, if we heat it sufficiently, be converted into vapour; and we have reason to believe that there is no substance which, if we could cool it sufficiently, would not both be liquified and solidified, though this has not yet been in all cases effected. There are many gases which we have not yet been able

to condense into a liquid or a solid; but if we were able to apply a sufficient degree of cold, or rather to abstract enough heat, from these bodies, we have every reason to believe that they would be convertible into solids and liquids. These three conditions of matter are what we may term functions of the temperature; that is to say, they depend entirely upon the temperature. For instance, I can show you that we can burn a piece of iron when we have the means, such as I have here, of producing a high temperature, hotter than anything we know, excepting the electric spark. [Professor Roscoe consumed a piece of watch-spring in the heat of the electric lamp, as though it were a piece of tinder, the corruscation of the sparks making this a very pretty experiment.] I can actually turn metal into vapour by means of the electric lamp, which gives not only a very bright light but an exceedingly high temperature. [The image of a piece of carbon was thrown upon the screen, and a small bit of silver having been placed between the poles of the lamp, the bright green streak of the silver vapour produced by its volatilization was distinctly visible.] I might go on showing you a great number of illustrations of this sort, to demonstrate that all bodies can be converted by temperature into vapour.

I stated at the beginning that we have by means of this spectrum analysis the means of detecting the composition of the sun and stars; but we have, also, the means thereby of ascertaining the composition, or chemical nature, of the earth, with a degree of accuracy beyond anything that chemists previously possessed. Allow me to illustrate this to you in another and familiar way, and the commonest illustrations are often the best. Suppose we were to visit the Manchester waterworks at Woodhead, which are so creditable to the corporation of this city, and so beneficial to its inhabitants, and were to throw a cartload of salt into the clear water, when that water reached us, after passing through all the ramifications of the supply pipes, I do not think that any one who drank the water would be conscious by its taste that a cartload of salt had been tumbled into the reservoir. In other words, our palates are not delicate enough to detect the presence of this small quantity of salt; but the chemist has other methods placed at his disposal, far more delicate than the human taste, for detecting the presence of salt. If I take one or two grains of salt, and put it into this large quantity of water, it is quite inappreciable to the tongue or palate; but if I use a more delicate test, I can detect the presence of even a fraction of a grain of salt. I will take a small quantity of nitrate of silver, and add it to the water in which I

placed the salt, and you will see by the light of this burning magnesium wire that the salt is made distinctly visible; whereas in the other vessel of water in which I placed no salt there is no such evidence, when I likewise add nitrate of silver. That serves as a simple and common illustration of this fact, and it seems to be one that you appreciate. Now let me put this case:—Suppose a chemist had so small a quantity of salt present in this bottle that his test with nitrate of silver failed to give him any reaction, he might say there was no salt there; but now spectrum analysis steps in, and shows us that all our chemical reactions have hitherto been only rough approximations to the truth, and we can by spectrum analysis show the presence of salt in this bottle. Thus the minutest trace of salt can be made visible in this non-luminous flame, composed of a mixture of common gas and air; and there is, probably, a small quantity of salt even now floating in the atmosphere. You notice certain yellow specks in the flame; those specks show that there is salt in the air. If I only rub my hands which have touched the salt, or even shake my coat over the flame, you perceive the yellow colour indicating the presence of salt. You must not suppose that I salted my coat beforehand. (A laugh.) Here we have the means of detecting substances by means of the colour which they impart to flame.

Now let us follow this out a little further, and for that purpose I must change my point of view, and ask you to accompany me in an examination as to the nature of the light from the sun and other bodies, in order that you may understand what makes the difference in the light of this gas flame when substances are burned in it. For this purpose, I will again make use of the electric lamp, the beautiful white light of which is due to the incandescence of pieces of carbon, or gas charcoal. I want to call your attention to the characteristic properties of this white light. It is to Sir Isaac Newton that we owe the discovery of the peculiar arrangement of colours in this white light. Sir Isaac Newton experimented with sunlight; but I cannot command sunlight in this room, and must therefore manufacture a light the nearest to it that I can. If I pass this white light through two triangular pieces of glass, called *prisms*, we shall see that it is built up of different colours. I have now passed the light through the prisms, and you perceive that it makes on the screen a brightly coloured band. This is due to the decomposition of the white light; that is to say, the white light is split up into this splendid rainbow, showing that white light is composed of varying tints, ranging from red to yellow, orange, blue, and violet.

I drew your attention at the beginning of the lecture to the fact that all bodies can exist in three states; and we find that those substances which are solids all give off the same kind of light. If I were to take a piece of metal, gold, silver, or platinum, and make it white hot, as I am now doing with these carbon points, the gold, silver, or platinum would each exhibit all these rainbow colours, and by this means I should therefore not be able to tell whether the substance were gold, silver, platinum, or carbon. This fact that white light consists of a number of different colours, although it was first made known by Sir Isaac Newton, in 1675, yet it is only within the last ten years, or less, that we have been able to make use of this important and interesting fact, by applying it to the discovery of the composition of the earth, and the sun, and stars. I should like to show you, by another simple experiment, that all these differently coloured rays when brought together again produce the effect of white light. This I can do by reversing the prism. In the first place, let me say that if I use no prism, we get on the wall a bright image of the slit through which the light passes. If I put one prism in, I get on the wall a bright spectrum, though not so extended as that which I obtain when I use two prisms. Now, if I allow the light to pass through the second prism placed in the opposite direction, you will see that I shall be able to get nothing but a bright slit of white light. Here you see the light coming through both prisms, but all the coloured lights on the wall are again converted into white light, by the reversal of the second prism. Now, I have again produced all the differently coloured rays by turning round the prism, and the effect is to show you that white light is a mixture of all these differently coloured rays. That is the conclusion to which Sir Isaac Newton arrived.

Now, let us pass on to the more immediate portion of our subject. I will strew on these carbons a small quantity of common salt. I will take with my knife a small portion of salt, and bring it on to one of these poles; and I think it will not take long to show you a considerable and remarkable change in the nature of the spectrum. You see that I have made a bright yellow line visible. I can show it to you better in another way. I will put a little of the common salt into the hole on the carbon, so that it may be held, and it will be turned into gas, by the heat of the electric arc. There! You see that instead of getting a continuous spectrum, we have a bright yellow band. It is a remarkable fact that sodium has the power of producing this bright yellow line; and what is more remarkable we find that no other

substance is capable of producing this yellow line. The metal contained in common salt is the only substance we know of which has this particular power. This peculiar yellow band would be much more distinctly seen if you could all look separately into the instrument called a spectroscope; I am at a great disadvantage in being obliged to show it to you all at once. In the instrument you would observe the yellow flame to be excessively thin, as thin as the thinnest spider's web; and yet it is always visible when any sodium is present.

So delicate is this reaction, that the first experimenters some years ago could not believe that this yellow light was due to the compound of sodium; but some thought it was due to water, whilst others did not know to what it was due. They could not believe that sodium was everywhere present; for you cannot leave a clean platinum wire exposed to the air for a moment without little particles of soda becoming attached to it. We have heard a great deal lately from Professor Tyndall and Dr. Angus Smith about the dust in the air, and this is a corroboration of the fact.

Sodium or common salt pervades the earth and air universally; it dances in the sunbeam, and we cannot get rid of it, do what we will. Now the light emitted by sodium is termed a monochromatic light; that is, it contains rays of one kind only; and I will show you that it is so by a very simple experiment. I have here a diagram containing large printed letters in various bright colours, which I am going to illuminate. When I take a little of this soda, and burn it, you will see that the diagram, and perhaps my face also, shows no trace of difference of colour, but is one uniform grey tint. (A laugh.) That proves that the light which the soda vapour gives off is made up of one kind of ray, and is therefore termed monochromatic.

Now, as all we have to do to be able to detect soda is to bring it into the state of vapour, so we have only to do the same thing when we want to detect the presence of any other metal, namely, bring it into a state of vapour, and examine its spectrum, that is, examine the light which the vapour gives off. You saw just now on the screen a beautiful green light which was caused by the vapour of silver; and if I now bring a small quantity of metal on to the poles of the carbon, you will see that the light consists of particular rays, the spectrum does not exhibit one continuous band, but is a broken one. You will readily perceive that this gives us a delicate means of detecting the presence of substances. Supposing, for instance, I want to detect silver, I have only to make it volatile and examine the

silver gas by means of this bright electric spark, by which I can produce a temperature sufficiently hot to volatilise almost any substance. What does this bright spark consist of? Simply of metals brought into a state of gas. If that light from this spark were sufficiently strong, it would enable me to throw upon the screen the bright lines produced by the metals which form the poles from which the spark is passing. I will now show it to you with the electric lamp, first an experiment with zinc, and afterwards with copper and brass. What I want you to understand is that no other substance but zinc has this power of producing these particular bright lines; so that wherever we see these bright lines, we are perfectly sure that zinc must be there present. [The experiment showed first the copper lines, then the zinc lines, and afterwards the lines of both these metals from the volatilization of brass. Having to experimentalise almost in the dark, Professor Roscoe had to ask for patience on the part of the audience for momentary delays in making the arrangements. We may say here that the utmost order, patience, and good humour prevailed throughout the lecture.] You now see how splendidly the red and blue bands of the zinc come out. Of course the effect is momentary, and not continuous, owing to the limiting conditions of the experiment. Now, I will try to show you the effect with copper. You will remember that I must change the copper into gas before I can exhibit the beautiful lines which the copper gives; and as it requires a very high temperature to fuse copper and convert it into vapour, and as I am at a considerable distance from the screen, I shall again have to tax your patience a little. I dare say we shall get it, but we shall have to boil our copper a little longer. (A laugh.) There! Now you see the beautiful green light of the copper, and now we have the lines of both zinc and copper as I have now placed a piece of brass on the carbon pole. I will now show you silver. There you see the bright silver lines. If I were to go on showing you all the metals, it would be the same, that is, each metal would exhibit special, peculiar, and characteristic bands. By such delicate test experiments as these, chemists have been able to detect no less than four new elementary bodies. They have discovered that one of these substances, lithium, which was thought to be a very rare substance, is really present almost everywhere. Lithium imparts to the flame a remarkably fine crimson tint, which you will see in a moment in the flame of the lamp on the table. This lithium, I repeat, was considered to be a very rare substance; but by means of spectrum analysis it has been found to exist everywhere. If you only hold

the ash of a cigar in the flame, you will see this peculiar red line in the spectroscope. I am afraid that the sodium which is present in the flame will rather neutralise the tint, nevertheless you will be able to see it. Why is it that we do not see the red flame more distinctly? It is because the red colour due to the lithium is mixed up with the yellow colour due to the sodium; but by means of spectrum analysis we can separate the red light from the yellow. The yellow light is more refrangible than the red light, and consequently, by means of the prism, we shall find that the sodium line takes one place, and the lithium line another; and the result is we have a beautiful red line alongside the yellow line. There you see the yellow sodium line; and there, on the right side, you see the red lithium line. You can now understand how the minutest trace—the millionth part or less—of a grain of lithium, can be detected, because the light which it emits is not interfered with by the yellow light, and, as I said, no other substance but lithium gives this splendid red line.

I will next show you a substance which has been newly discovered. It is called *thallium*. It is an elementary body, and was discovered by an Englishman, Mr. Crookes. Two new elementary bodies had previously been discovered in the same way by a great German chemist, named Bunsen, the discoverer of two new alkaline metals resembling potassium, the metal contained in common potashes, and which he would have been unable to detect, had it not been for this wonderful spectrum analysis. I am going to show you the spectrum of thallium. You will see a brilliant green line, from which it takes its name, derived from the Greek word thallus, a green twig. That green line indicates the presence of a new body; it tells us a secret—that of the existence of this new substance to which the name of thallium has been given. No other body gives this green line but thallium, and no other body gives this yellow line but sodium, or this red line but lithium.

Now, you will, I hope, be in a position in some degree to understand how it is that the light of the distant sun can be analysed, a body so distant that if we had a railway from here to the sun, and we were to travel as passengers at the rate of 40 miles an hour—which railway directors tell us is about as fast as is consistent with safety—it would take us about 300 years to get there! Light travels at the rate of 192,000 miles in a second, and consequently it does not take more than eight and a half minutes for the light of the sun to reach us. You will now readily understand how this spectrum analysis enables us to judge what there is in the sun, because if I saw this yellow line in the

sun's rays, or this green line, I should infer that the substances producing these lines existed in the sun. This would appear to you still more striking if I could show you the lines caused by the vapour of iron, and many other metals, all producing lines of different degrees of breadth and luminosity. Spectrum analysis enables us to test in the same way the light of the fixed stars, although they are at such an inconceivably much greater distance than the sun. If I discover the yellow line in the starlight, I infer the presence of soda. It does not matter whether the flame which I analyse is five inches from my eye, or five miles, or five millions of miles, or five millions of millions of millions of millions of miles! If I can by means of the prism perceive certain well-known lines, I am justified in inferring, with scientific certainty, the presence of the corresponding substances. I say I am as certain of my conclusion in this case as I am of any other question in natural science. I apply certain tests to a mineral sent to me from New Zealand, and I come to the conclusion that the mineral is iron; and nobody doubts it. But somebody might say that if other tests had been applied, I should have found that the mineral was not iron. Still, having applied all the means in my power, I find that the effects correspond with those produced by iron, I am scientifically logical in asserting that the substance really is iron, and so for the existence of iron in the sun, all I can say is that if I apply these tests and the result is invariably to show the presence of these lines of light, indicating the existence of iron in the sun, I am as philosophically and scientifically correct in my inference that iron exists in the sun as though I had seen and handled it.

Let me now try to explain to you what we see in the sunlight. This will be the second part of my lecture, and I shall not detain you much longer, because I am simply making this part of my lecture introductory to Mr. Huggins's. What do we see in the sunlight? Do we see the same bright uninterrupted band that we have noticed here? No, we do not; we have something different. I cannot show you sunlight now, but I will try to explain what it is we see in the sunlight, when we look at it through an accurate instrument. I have here a picture, or diagram, which will serve to show the kind of thing we see in the sunlight. I use the common means of the magic lantern to show this picture, which is roughly prepared and imperfectly coloured, but it will serve you that the solar spectrum is a coloured band, from red to blue, as in the electric spectrum, but with this addition—that it is intersected with *dark lines*. These dark lines are always present in the sunlight, though Sir Isaac

Newton did not see them. They were first mapped by a German optician, named Fraunhofer, and these lines are known as *Fraunhofer's lines.* Ten years ago nobody knew what Fraunhofer's lines were; they were a kind of sphinx amongst opticians; nobody knew what these black lines in the sunlight denoted. They were always found, whether in direct or reflected sunlight, whether in the light of the sun or in the light of the moon, or the planets Venus, Mars, Jupiter, &c., which, you know, reflect the light of the sun. So long ago as 1819 Fraunhofer found that although there are dark lines in starlight, yet they do not exist in the same number and proportion in starlight as in sunlight; the stars shining, as you are aware, by their own light. He therefore came to the conclusion that these dark lines were caused by something which existed in the sun and the stars, and was not due to anything in our air, else why was starlight different from sunlight, both having to pass through our air? I will show you a drawing made by Fraunhofer, exhibiting the black lines, of which there are thousands in the sunlight, and they are nothing more than parts of the sunlight where a particular kind of light is wanting, and therefore there is a black space or line; and these lines are so numerous that they appear nearly to fill up the whole space, and are yet so thin that they do not appreciably detract from the total amount of light that comes to us.

What causes these shades in the sunlight? The great discovery of the cause of these dark lines was made by a German, Professor Kirchhoff. In matters of science we have been very much indebted to the Germans, and but for their laborious and intellectual labours we should be wanting in many valuable discoveries. Of late they have been taking the lead in war as they have long done in their knowledge of Nature. Professor Kirchhoff, working quietly in his laboratory at Heidelberg, was able to explain this enigma of the dark lines in the sunlight. He discovered this long-kept secret of nature, and told us what these dark lines really mean. Kirchhoff found on examining these dark lines that certain of them correspond exactly with those beautiful bright bands which I have endeavoured to show you on the screen. He observed that every one of the hundreds of bright lines in the iron spectrum had its corresponding dark line in the sunlight. How was this? Why should these lines all exactly coincide. I will endeavour to show you the correspondence between these dark lines in the sun with the bright lines of the iron. There! these are maps of sunlight uncoloured, for we only desire to show now the position and breadth of space occupied by these dark lines.

Below these you will see a number of smaller lines which indicate the position of the bright iron lines. I was fortunate enough myself some years ago to see this thing with my own eyes. I am privileged to reckon Kirchhoff and Bunsen among my intimate friends, and I was visiting them when they were making these interesting discoveries. When they showed this thing to me it flashed upon my mind at once—there is iron in the sun!—because for every one of the bright iron lines there was a corresponding dark one seen in the solar spectrum. Understanding this remarkable coincidence, the only question we need now to ask is—How is it that if there is iron in the sun we do not see these lines *bright* but *dark*? How is that? That is the only point which now remains to be answered. I will endeavour to show you an experiment to prove to you that we can make these bright lines dark, and I will try to show you that I can make artificial sunlight so far as regards the formation of one black line, and that I can get in place of the bright yellow sodium line a black line. I can only show this in the case of sodium, but the same thing holds good for all the other metals. I am going to burn a little sodium, and I want you to notice that on the part of the screen where you saw the yellow line you will see in its place a black one. By that experiment I have, in a rude and imperfect way, manufactured sunlight. There you see the black line between the two yellow ones. There is a black line where the sodium ought to be, and as that absorbs the sodium, it is that black band which appears in the sunlight. The same thing takes place in the sun. It seems very singular that the sodium vapour, which gives off a yellow light, should absorb yellow light; and yet nothing in reality is more true, or more likely, from being in accordance with many other facts in science.

Now, we know from astronomical and other observations that the temperature of the sun is exceedingly high. Things which on the earth are solid and liquid are in the sun gases. Therefore, we do not need to wonder at finding iron in the sun in a state of gas, for the temperature of the sun is far higher than the temperature of this electric spark, or of the oxy-hydrogen flame in which I burned iron just now. It is this iron and sodium and other elements in a state of vapour which have the power of absorbing the exact kind of light which they give off; and the consequence is that instead of showing bright lines in the sun you see dark ones. As if to render this explanation still more easy of our acceptance, science has helped us again by a recent discovery in regard to the appearance of the sun during a total eclipse. Some

very extraordinary appearances present themselves when the sun is totally eclipsed, and I hope that after Christmas I shall be able to announce to you that we shall have a lecture on the forthcoming eclipse of the sun from Mr. Lockyer. The extraordinary red flames or prominences which shoot out from the sun are only visible during an eclipse, and many of us are going to Sicily shortly to see that phenomenon. These red prominences are due to the ignition of hydrogen gas, and they give bright lines instead of dark ones, exactly like those you saw on the screen. These red flames shoot up some 80,000 or 90,000 miles above the surface of the sun, and they are due to the presence of glowing hydrogen. I am going to show you some glowing hydrogen. I have here in this glass tube hydrogen gas, and when I heat it by an electric current, you will see the beautiful colours due to the glowing hydrogen, and identical with those of the red solar prominences. That beautiful red colour on my right is the colour we see in a total eclipse when the red prominences shoot out. These red prominences then consist of glowing hydrogen.

And now, suppose you ask me—What of all this? How much better shall we be for knowing that there are these new elements in the earth, or that lithium is present everywhere, or that iron and hydrogen are contained in the sun and stars? What am I to say to you? Why, I will begin by telling you the story of that good old American philosopher, Benjamin Franklin, who, like the fabled Prometheus of old, first brought lightning down to the earth by the string of his kite. He was asked this question of his discovery, and he answered, "Tell me the use of an infant." "Make it of use." So in science, the infant truths must be made useful. Neither you nor I perhaps can see the *how* or the *when*, but that the time may come at any moment when the most obscure of nature's secrets shall at once be employed for the benefit of mankind, no one who knows anything of science can for one instant doubt. Who could have foretold that the discovery that a dead frog's legs jump when they are touched by two different metals should have led in a few short years to the discovery of the electric telegraph? Who could have imagined that a chemical compound, a few years ago scarcely known but to a few scientific chemists, should turn out the greatest boon ever bestowed by science upon suffering humanity? We all now know the value and uses of chloroform. So I might go on through all the different branches of science, unfolding to you, in endless variety and number, instances of the direct benefit of scientific discovery

Enough, surely, has been said to satisfy you of the national importance of science and of scientific research.

But apart from the *usefulness* of science in the sense which I have here employed—by which I mean its application to raising the material welfare of mankind—there is another and a higher part for science to play, namely, to enlarge the understanding and to purify the hearts of men. To the study of nature men may always look as a source of pure, unalloyed enjoyment, a spring which is never dry, a food which never satiates. What gives zest and spirit to that poor weaver's life, who walks for miles after his hard day's work—as many do—to secure a rare fern, or find a new coal fossil? Does he earn a farthing more? Will his master pay him more wages? Or can he thereby "turn an honest penny," as it is termed? Not he. His aims are loftier and nobler. His prize and payment is a far higher one—that of an enlarged mind and a peaceful heart. His thoughts are raised above the mere struggle for wealth and position. He lives quietly and contentedly, and finds in the pursuit and study of nature that peace and happiness which alone such studies can give.

It is with the hope that some few may be induced to take up scientific pursuits that these lectures have been arranged. We all know how in England political power is gradually being transferred to the masses of the people. Whether that transference proves a blessing or a curse depends on the people themselves. A people whose masses are without knowledge and without tastes for higher things than the mere struggle for existence can come to no good. The Education Bill passed last session will, let us hope, secure for every child the rudiments of education; but to elevate the tastes of the people, to show men how debasing are the habits to which many of them are chained, and to point out the direction in which they must tread in order to be true and happy men—this is even a more difficult and tedious task.

If this course of Science Lectures to the People helps even in the slightest degree to advance this, perhaps, the greatest necessity of our land and of our time, the labours of those who are engaged in giving them will not have been bestowed in vain.

On the motion of the Rev. S. A. Steinthall, hearty thanks were given to Professor Roscoe for his interesting and instructive lecture, and for the trouble he had taken in arranging the present course of lectures and classes

SPECTRUM ANALYSIS,

IN ITS APPLICATION TO THE HEAVENLY BODIES.

A LECTURE

BY

WILLIAM HUGGINS, LL.D., D.C.L., F.R.S.,

Delivered in the Hulme Town Hall, Manchester, November 16, 1870.

I HAVE to describe, this evening, some of the most important of the recent additions to our knowledge of that vast array of luminous orbs which have been in all ages a beauty and a mystery to mankind. Last week, my distinguished friend, Professor Roscoe, gave in this room an account of the principles of the new method of investigation, spectrum analysis, which may be said, with but little exaggeration, to have given to man a new sense. But great as is the value of the searching power of this method of analysis, as applied to terrestrial substances, by which there have been revealed to us four entirely new kinds of matter, the metals rubidium, cœsium, thallium, and indium, it is in its application to the heavenly bodies that this method of research has produced the most remarkable results. This new mode of investigation is peculiarly adapted to the needs of the astronomer, since the only requisite is light; and it matters not how great the distance that light has come, nor how long it has been upon its way; the spectroscope places within his reach certain knowledge on many points on which before all we could hope for was a mere probability or conjecture. The chemical nature, the physical constitution, and, within certain limits, the temperature, and the density, and the motion of the line of sight of the most distant parts of the visible universe can now be investigated in the observatory; and in respect of some of the heavenly bodies, considerable information has been obtained on these points.

Before describing the results obtained when spectrum analysis is applied to the heavenly bodies, I would recall to your recollection, in as few words as possible, the principles of this method of analysis, as explained in this room last week. The prism, or the spectroscope, enables us to see, in succession, and so to discriminate the different kinds of light which may exist together in the radiations of a luminous body, and which without the intervention of the prism would fall simultaneously upon the eye, and so be lost in a common impression. These different kinds of light, existing together in the radiation of a luminous body, when they are thus separated by the prism, so that the eye can discriminate them, form the spectrum of that light. All the different kinds of spectra which are observed from different luminous bodies may be very conveniently arranged in three classes. I shall now exhibit to you a spectrum representing each one of these three classes; but before exhibiting upon the screen the first spectrum, I wish to show upon the screen the luminous source from which the light has come. That is of importance. In this case the luminous source will be two pieces of carbon rendered incandescent by means of electricity. Part of the electricity is converted into heat by the resistance of the carbon. The carbon is not burning; it is merely rendered white hot. We now see upon the screen the images of two small pieces of carbon rendered white hot by the electric current. At the present time there are upon that screen all the gorgeous colours of the rainbow, but you cannot see them. Why? Because they all fall together exactly upon the same spot; they all enter the eye together; and the impression that we receive is that of all the colours together at the same moment, and such a compound impression we call "white" Now the same light which is falling upon that screen will be thrown upon this screen after having passed through two prisms. You there see this beautiful object, and you would see it much better if we could have the room darker. [The gas was lowered still further and the beautiful effect of the colours thereby heightened.] There are not more colours on this screen than on the other; the only difference is that the prism has separated the colours, so that they fall on different parts of the screen, and the eye can view them in succession, thus discriminating the different kinds of light. You perceive that in that spectrum the colours are complete from the red to the blue, and it is therefore called a "continuous spectrum," and such a spectrum indicates that the light is derived from incandescent solid or liquid bodies, as you saw was the case when the source of the light was thrown on the other screen. We will now throw upon the other

screen the same points of carbon as before, but before allowing the electricity to pass through them, we will place a small quantity of chloride of lithium on one of them, and you now see that the points can be separated, because the chloride of lithium is decomposed, and the lithium volatilised, and you have a beautiful arc of red luminous vapour between the two points. The lithium is not burning; it is simply converted into vapour, and the vapour become so hot as to be luminous In this case nearly the whole of the light comes from the luminous vapour. There will now be thrown upon the other screen the spectrum of this light from the luminous vapour of lithium, and you will see that we shall have an entirely different form of spectrum. There will be a little of the continuous spectrum that you saw before, because the carbon points are also present, and though less intensely luminous, still they are adding a certain amount of light. You see that nearly the whole of the light now consists of three bright bands, two in the red, one in the green, and one in the extreme blue. These colours represent the light which together entered the eye from the red vapour that was seen upon the other screen. In this case the spectrum is not continuous; the colours are separated; and when we have such a spectrum it is called a spectrum of bright lines, because the width of the coloured bands depends upon the narrowness of the slit in the apparatus. With the best arrangements the bright lines would be still narrower. When we have such a spectrum of bright lines, we know that the source of the light is luminous vapour or gas. As you were informed last week, each terrestrial substance gives a set of these bright lines peculiar to itself; so that when we see these particular lines upon the screen, we know for certain that the source of the light is the incandescent vapour of this metal lithium. In this way, when certain bright lines are seen in the spectra of the heavenly bodies, if these bright lines coincide with the set of bright lines given out by any terrestrial substance, we then know that this terrestrial substance is really present in those distant bodies. The third class of spectra are spectra which have been modified, or altered and changed, in some respect, on their way to us. The light at its origin would be from an incandescent solid, and would give continuous light; but the light on its way to us has passed through a certain vapour, say sodium, and that vapour stops out a certain portion of the light, and the part of the light which it stops out is of a particular colour, is precisely of the same part of the spectrum which sodium would emit if sufficiently heated. To show this, there will be thrown upon the screen the continuous spectrum of the carbon points; and Professor Roscoe will kindly convert a small piece

of sodium into vapour, and cause the vapour of the sodium to come upon the screen, and the result will be a black line where the yellow point would have been if the luminous vapour of sodium had been employed. The spectrum containing these dark lines shows that the light has been modified on its way to us, and has suffered absorption by passing through a certain vapour. As this dark line corresponds in position to the bright line from sodium, it is easy, by comparing the set of dark lines as seen in the spectrum of the sun or stars with the set of bright lines given out by any terrestrial substance, to determine whether that substance is one of the vapours or gases through which the light has passed. If the dark lines coincide with the bright lines, we then know that the absorbing gas is the vapour of the terrestrial substance which we have under examination. Kirchhoff applied this investigation to the sun; and he gave us the first certain knowledge of the constitution of that body, showing that it consists of matter similar to that which exists upon the earth, and that at so high a temperature that such metals as iron, nickel, magnesium, and zinc exist there in a state of gas or vapour.

This was the state of this newly-born science of Spectroscopy when in 1861, in conjunction with my late distinguished friend, Dr. William Allen Miller, I endeavoured to extend this analysis to the other heavenly bodies. And here some formidable difficulties presented themselves. Though the stars appear to shine very brightly in the sky, yet the amount of light which enters the eye from a star is exceedingly small. It was therefore necessary by some means to increase the amount of light which enters the eye from the stars. This was accomplished by the use of a large telescope, so that the whole of the light which falls upon the object-glass, 8 inches in diameter, is gathered up and concentrated into a bright point, and is thus enabled to enter into the eye. It may be well to state that a telescope has not the same light-gathering power, in respect of an object of sensible size, as a nebula or planet, because the image of the nebula or planet is as much larger than the image formed by the unarmed eye, as the instrument gathers more light; but as stars remain in the telescope as minute points of light, it is possible, by means of a large mirror or a large lens, to increase their brightness many thousand times.

Another difficulty presented itself in the apparent motion of the heavenly bodies. When we look up to the sky, the stars appear to be standing still; but it is for the same reason that the hands of a watch appear to be stationary. A few seconds suffice to show that the hands of the watch have moved; and a few

minutes will be sufficient to show to any careful observer who has taken the precaution to notice the particular direction of a star to a fixed object—as the edge of a wall or the point of a steeple—that the stars also move rapidly from east to west. This motion is not real but apparent, and it arises from the rotation of the earth, which is sweeping us round towards the east, and thus causing the stars to appear to move towards the west. Hence it is obvious that if the telescope be fixed to an axis, and the axis be placed parallel to the axis of the rotation of the earth, and then that this axis be made to move round by a clock motion with a speed exactly the same as that with which the axis of the earth turns, that the telescope will be moved towards the west with the same speed with which the earth is moving towards the east; and in this way a star may be made to appear stationary in the telescope for hours together.

There will now be thrown upon the screen a view of the interior of my observatory. There you see the telescope; here is the axis parallel to the rotation of the axis of the earth; and there the clock motion by which the telescope is moved. Those wires are connected with a powerful conducting coil, and this again with batteries, for the purpose of obtaining a sufficiently high heating power for converting metals into vapour; and thus the bright lines produced by the vapours of iron, nickel, &c., could be directly compared with the lines as seen in the stars. The most convenient way of converting these metals into vapour is by the apparatus I have here—an induction coil. Between one of the poles is placed some lithium, and between the other some of the metal thallium. I will cause the sparks to pass, and you will see that they are beautifully green. It is green because a portion of the metal thallium has been converted into vapour; the light emitted is from the vapour of thallium. I have here another, which is arranged with a portion of lithium between, and in that case the light is red, that being the colour of the vapour of lithium. [These and all the preceding and subsequent experiments, superintended by Professor Roscoe, were very successful, and it was often impossible to suppress the applause of the audience.]

In the picture of my observatory, still on the screen, you see the observing chair, whence the observer, by touching a small button, could at any moment, by means of the apparatus, bring into view with the spectrum of a star the spectrum of iron, magnesium, or any other terrestrial substance, and see the two simultaneously side by side. In this way it was easy to determine

with accuracy whether a group of bright lines as are produced by magnesium were coincident or not with a similar set of bright or dark lines as seen in the spectrum of the heavenly bodies.

When we look up to the heavens on successive nights we do not fail to observe that some two or three of the brighter stars are found to be moving amongst the vast host of stars Such stars were noticed by the ancients, and were called by them "wandering stars." We have adopted the term, and call them "planets;" and we now know that together with the earth they revolve about the sun, and shine only as they reflect his light. The spectrum, therefore, of a planet or of the moon would be the same as that of the sun; it would, indeed, be a spectrum of solar light reflected from a planet or from the moon. Therefore all the information we could expect to obtain by examining the spectrum of the moon or of a planet would be the modification or alteration which had been produced in the solar light by the absorption of atmospheres which might exist about those bodies. Now the atmosphere of a planet is capable of producing such an absorption. We have certain evidence of this in the effect produced upon the solar light by the atmosphere of the earth. You now see upon the screen a spectrum showing a number of dark lines, which are added to the solar spectrum by the absorbent action of our atmosphere. When the sun is near the horizon, so that his light passes through a greater extent of the earth's atmosphere, and especially through the vapour near the earth's surface, we get these additional dark lines; but as the sun rises higher in the heavens, these lines become fainter and fainter, until at last they nearly disappear.

There will now be thrown upon the screen, in succession, telescopic views of two or three of the planets. You have now upon the screen an appearance of Jupiter, as seen in a large telescope. There you see those strange belts across, which may be masses of clouds, dependent upon fixed currents of air similar to our trade winds. When the spectrum of Jupiter was viewed I saw three or four strong lines, one of them coincident with a strong line produced by the earth's atmosphere, showing that this planet has an atmosphere similar to that of the earth, but not identical with it.

There you have the telescopic appearance of the planet Mars. Here again we have great similarity to the earth. You see that white spot at the top of the diagram. We have certain evidence that that is an accumulation of ice, because it is seen to diminish and increase as that portion of Mars is more or less illuminated by the sun. The spectrum of Mars shows also that this planet has an atmosphere similar to that of the earth.

. There is now thrown upon the screen a view of the most beau tiful of all the planets—Saturn—with its rings. This planet also gives lines, and similar lines are noticed in the rings of the planet, so that it is obvious that both the ball and the ring are surrounded with an atmosphere.

We must now pass from these near bodies, the moon and the planets, into the remoteness of space, to the true stars, which are self luminous bodies, and which are so far off that we are quite unable to form a proper conception of the distance which separates them from us. Sir John Herschel has suggested the following illustration of the size of the solar system:—If you place a globe, two feet in diameter, in the centre of a large plain, to represent the sun, then the earth could be represented by a pea placed at a distance of 215 feet from it, Jupiter by an orange placed at a distance of a quarter of a mile; and Neptune, the most distant of the planets, by a plum at a distance of a mile and a quarter. But Sirius, one of the brightest of the stars, would, upon the same scale, have to be removed to a distance of forty thousand miles, or five times the diameter of the earth. So that the earth is not one-fifth part big enough to hold even a model to represent the distance of the stars, on a scale the same as that on which the earth itself would be represented by a pea. And yet the power of this new method of analysis can bridge this enormous gulf of space, and we can analyse these distant bodies with almost as great a certainty as we can the vapour of any metal on the laboratory table.

There will now be thrown upon the screen the spectra of two stars which we examined with very great care, the stars Aldebaran and Betelgeux now visible in the south-east. The spectra resemble in general character the solar spectrum. You observe a number of dark lines, which are not the same in both spectra. They are grouped differently, and underneath each spectrum you will see a number of white bright lines. Those white lines represent the bright lines of the terrestrial substances which I compared directly with the spectra of the stars by the method which I have described; and in the case of many of the metals complete coincidence was established. For example, in the case of this double line of sodium. Sodium gives a double bright line; and there was seen to be a double dark line in the spectrum of that star coincident exactly with the double bright line of sodium. So again the triple green line of magnesium was found to coincide, line for line, with the triple dark line in these two stars Five bright lines of iron were found coincident with the same number of dark lines. The lines of hydrogen in one of the stars were found coincident with

two dark lines in one of the stars. In this way the presence of seven or eight terrestrial substances were ascertained to exist in these distant bodies. We thus learn that the stars have a community of matter with the earth; that the matter of which they are composed is of the same order as that of the earth; that it is subjected to the same force—the force of heat; and that it emits light in the same way as terrestrial substances. It should not be forgotten that before these investigations we had no certain knowledge of the true nature of the stars; it was merely as a matter of analogy that they had come to be considered as suns similar to our own sun. In this way some fifty of the stars were examined, and they were found to differ one from the other, but were all formed upon the same type; all contained some terrestrial substances, but apparently in different proportions; and containing, it may be, many other new bodies. Many of these lines which are not found to be coincident with terrestrial lines may be indicative of some forms of matter entirely new to us; but at present it is impossible to recognise these substances so as to know what they are. It may be worthy of remark, that the elements which are essential to life, as we know it upon the earth, and which would be most easily recognised in the spectroscope—such as hydrogen, magnesium, iron, and sodium—these were, with possibly one or two exceptions, found to be present in the spectra of all the stars which we examined. Now, many of the stars are seen to differ very greatly in colour, and especially is this the case when the telescope is employed. Many stars which to the naked eye appear single, when the telescope is directed to them are seen to be composed of two stars, beautifully contrasted in colour. There is now thrown upon the screen, and I hope visible to the greater part of the audience, the appearance which the star Beta in the Swan exhibits when viewed through a large telescope. The orange star has a very beautiful bluish purple companion. Now, it seemed probable that as the spectra of the stars are crossed by these dark bands, that if they were found to exist in groups and were not scattered evenly over the whole spectrum, but crowded together in some places more than others, then those parts of the spectrum where the strongest lines occurred, or where the lines were most numerous, would become dim, and these colours would be darkened relatively to the parts of the spectrum where few lines occur; and hence these latter colours would tinge the stars with their own tints. And this speculation was found to agree with observation. We now throw upon the screen the spectra of the two stars which you have just seen. The dark

lines, you will observe, occur for the most part in the blue and red ends of the spectrum, leaving the orange part of the light almost undimmed; hence the orange light predominates in the star, and the star instead of being white becomes tinged with orange. In the lower spectrum a number of absorbent lines occur across the orange part of the spectrum; hence the red and the blue predominate; and the result is that beautiful bluish purple colour which you saw upon the screen. I will give one more illustration. The brightest of the two stars forming Alpha in the constellation Hercules is a double star, and the brighter of the two component colours has an orange tint. In this exceedingly beautiful spectrum you see that the orange part is comparatively free from dark lines of absorption; therefore that colour predominates in the light of the star.

A phenomenon observed among the stars of great interest is the periodical waxing and waning of their light. Many of the stars have shorter or longer periods, through which their light increases or diminishes. This phenomenon, which has been studied with great success by your distinguished townsman, Mr. Baxendell, is one upon which spectrum analysis will probably throw much light. Up to the present time we have not gained much information; but I will throw upon the screen the spectrum of one of the variable stars, representing an appearance which is seen in many of these objects. The spectrum now upon the screen is that of the star named by the Greek letter μ in the constellation of the Whale. It is not known at present whether these variable stars are related to a phenomenon of very rare occurrence—namely, the sudden outburst in the sky of bright stars. Such a phenomenon has been seen occasionally, but it is only a few generations of mankind who are fortunate enough to be witnesses of this rare sight. Most fortunately a grand example of this class of stars burst into sudden splendour in the year 1866. I think it is probable that these are not new stars, but that they are small stars which have burst into sudden splendour; and though their splendour has been temporary, and has soon dwindled down into insignificance, it is probable that they have not become entirely extinguished, but still exist in the sky, and perhaps at some future period they may again burst forth into unwonted splendour.

In 1866 such a star shone out with great brilliancy—a star, I believe, of the first magnitude, in the constellation of the Northern Crown. It was first observed by Mr. Birmingham, in Ireland. He kindly wrote to me, and I was enabled to examine its spectrum before it had much diminished. The spectrum of that star is now thrown

upon the screen. I think, without a word from myself, you will see that the spectrum presents one peculiarity entirely different from the spectra you have already seen. In addition to the continuous spectrum and the dark lines, you see that there is a group of bright lines. Now this shows that the light which comes to us from this star has had a double origin; that part of it has come from an incandescent solid, and has passed through absorbent vapours, just as the light of the stars and sun: but that, in addition to this light, there is a light that has come to us directly from some luminous gas, and which forms the spectrum of bright lines. I found by direct comparison that two of these bright lines, and probably a third, coincided exactly with the bright lines of hydrogen, and we therefore know that this star must have been surrounded by an atmosphere of hydrogen so intensely hot as to be luminous. This phenomenon becomes of more interest from the results of recent observations, to which I shall presently refer. We now know that the sun is surrounded by luminous hydrogen, that the red prominences seen in a total eclipse of the sun consist for the most part of this intensely heated hydrogen; therefore, bright lines similar to these are always present in the solar spectrum, but we do not see them. Why? Because the luminous hydrogen round the sun is very faint as compared with the great intensity of the photosphere, or that part of the sun which gives a white light. Consequently, all these lines can do is to render rather less dark the lines of the sun which coincide in position with them. But when we look at that part of the sun where there is no bright photosphere to overpower the hydrogen—as, for instance, the dark part of the solar spots—then these bright lines become visible. Hence we learn that in this star the atmosphere of hydrogen must have had a very great intensity relatively to the brightness of the photosphere. And there have since been discovered two or three other stars in which this state of things appears to be permanent, at least of no very temporary character. In what way this atmosphere of intensely heated hydrogen has got round these stars we do not know— whether it was an outburst from the centre of the star, which we must suppose is hotter than the surface—whether it was thus a mass of much hotter hydrogen burst from the sun, or whether, which is far less probable, in some way a combustion had been set up, and in this way the hydrogen become heated, we cannot say.

Now we will leave the stars for some other objects seen in the heavens—objects less familiar to you, because they are not to be seen by the common gaze, but a telescope is necessary to discover

them. When a telescope is directed to the sky there are seen to be amongst the stars a number of patches of luminous matter, faintly shining clouds, with small wisps of light, sometimes of fantastic forms. These have great interest for us, because they are not similar to any parts of the solar system; and, therefore, from analogy we have no clue to their nature. What are they? Are they great companies of suns so distant that their individuality is lost in the common blaze? Or are they portions of the original and unformed material of the universe? Are they some of the bricks and mortar out of which the heavens and the earth have been made? How much light could be thrown upon these bodies if only we could examine their spectra. This has been accomplished. In 1864 I was successful in examining the spectrum of one of these objects. I have now thrown upon the screen the telescopic appearance of one of these objects. You have there a very good representation of the appearance presented by the nebula called the "dumb bell nebula," as it appeared in the telescope of Lord Rosse. There will now be thrown upon the screen the appearance presented when the light of one of these objects was analysed by the prism. You see now something perfectly unlike the spectrum of a star—no continuous spectrum from red to blue, with a number of dark lines; but in place of that three brilliant lines in the middle of the spectrum, a green line and then two lines further towards the blue. This showed at once that the nebula was not a group of suns, was not made up of stars, but that it was a mass of luminous gas. The next thing was to examine the position of these lines, and the result of that examination will be shown in the next diagram. One of these bright lines was found to be coincident with the brightest lines of the gas hydrogen; another line, the brightest of the three, was found to be coincident with the brightest lines of the gas nitrogen; the third line was not coincident with any substance which was compared with it, though it was very near the bright line of thallium. We thus learn that these nebulæ consist for the most part of two gases, hydrogen and nitrogen; and that these are so hot as to emit light—to be luminous. If you ask how it was there was only one line of each gas—since hydrogen and nitrogen give spectra of several lines—we cannot answer that question with certainty. I may state, however, that I found that when the light of hydrogen and nitrogen was diminished in any way by moving the spark from the gas to a greater distance from the slit, or by the interposition of a neutral tint gas, then all the bright lines of these gases became extinguished, with the exception

of just one line; and the one line in each gas which remained was precisely the one line coincident respectively with two of the lines of the spectrum of this nebula.

I will now call your attention to that nebula which we have upon the screen. This is a very remarkable one, as it shows that wonderful spiral structure which is so characteristic of some of these bodies, a sort of double spiral. In the spectrum of this object I was enabled to detect a fourth line, and that fourth line—which extends further into the blue part of the spectrum—is probably coincident with another of the lines of hydrogen.

You have now upon the screen one of the most interesting of the nebulæ—the Ring nebulæ in the constellation of Lyra. This nebula looks very much like an oval bird's nest. I found that the faint light in the interior of the Ring gave the same spectrum as the brighter portions of the margin of the object.

There is another of these remarkable objects. That gave also a spectrum of three bright lines. Here you have another resembling very much the planet Saturn, seen edgeways; that gave also three bright lines. These are given as illustrations of the various forms presented by the nebulæ.

It was interesting to observe the spectrum of the nebulæ which had been resolved by the telescope into discrete points of light; and in this case it was found that the spectrum was continuous. There are some few nebulæ which have not been resolved by the telescope, but which have given a continuous spectrum. One of these is now upon the screen—the great nebula in Andromeda. This may be seen as a small cometary object with the naked eye. It is favourably situated for observation now at ten o'clock at night, if you look exactly in the zenith, just south of two small stars. This gives a continuous spectrum, and upon comparing the results of some sixty or seventy of these bodies with telescopic observations on the same nebulæ by the late Lord Rosse, it was found that as a rule the nebulæ which had been resolved by the telescope gave a continuous spectrum, while the nebulæ which had not been resolved by the telescope gave a gaseous spectrum.

We must now pass again to another order of the heavenly bodies, objects which appear suddenly, possess strange and rapidly changing forms, and which in all ages and amongst all peoples have been regarded as signs and portents of war and common calamities. Up to the present time, only five comets have been examined with the spectroscope. In 1861, I was

enabled to observe a telescopic comet in this way, and I found that the nucleus was distinct from the light of the sun; that it was not merely reflected solar light, but gave one or more bright lines. In 1868, a more complete examination of one or two comets could be made; these comets, however, were telescopic, invisible to the naked eye. The appearance presented by one of these in the telescope will now be thrown upon the screen. The slit of the spectroscope was placed across the head of the comet, so as to examine the light of the nucleus. The central part of the head is called the "nucleus;" around it is the "coma," or hair of the comet; and behind is its "tail," always in a direction turned from the sun. There will now be thrown upon the screen the spectrum of this comet, and also the spectrum of another comet observed about the same time. This was the periodical comet of Brorsen, and the other was a small comet discovered by Dr. Winnecke. The spectra of both are similar. Both consist of three shaded bands of light, but the positions of the bands are not identical in the two comets. This was the light from the head of the comet. The tail of the comet gave apparently a continuous spectrum, and may have been merely reflected solar light. Now, on the evening I made that observation, I suspected that the spectrum resembled very closely the spectrum of carbon, as I had observed it some two or three years before. The next evening I compared directly the spectrum of carbon with the spectrum of this comet. The spectrum of carbon is represented in the two upper spectra. Both these are identical as regards the green bands; they differ only in one point, namely, in one of the spectra the bands of light can be resolved into distinct lines; in the other spectra the light fades gradually. Now in the light of the comet no such lines were seen· and when the electric spark is taken in a gas containing carbon—olefiant gas for example,—such a spectrum is obtained. On the second evening, therefore, I made some olefiant gas, and fitted up an apparatus so that I could take the electric spark in this gas, and that light was reflected into the spectroscope when fixed to the end of the telescope; and in this way I could see at the same moment the spectrum of the comet and of the olefiant gas, and the appearance presented was exactly the same as you have it on the diagram. You will see that the bands of the second spectrum coincide exactly in position with the bands in the spectrum of the comet; they begin and end at the same part, and the coincidence in every respect seems to be complete between the light of that comet and the light obtained by passing a spark in olefiant gas. It seems almost certain that this spectrum is that of carbon,

because a similar spectrum is obtained when a gas is viewed in which no hydrogen is present. Now the obvious conclusion would be that this comet consisted of luminous vapour of carbon. This, however, is an exceedingly difficult supposition. There are many reasons why we can hardly conceive such to be the case, unless carbon exists there in some other form or allotropic state to that in which we know it upon the earth.

In the next diagram you have the appearance presented when the head of the large comet of 1858 was viewed in the telescope. And this is of great interest in connection with the point upon which I am now speaking. That is the head of the great comet of 1858. It shows an exceedingly bright envelope, then a dark envelope, then a bright one, and then comes the tail; and the *modus operandi* seems to be that as the comet approaches the sun, the nucleus throws out a certain amount of luminous matter, which becomes dark and then luminous again, and then forms the tail. It may be that if the nucleus is self luminous that it throws out some luminous gas; then that it becomes so far cool that it cannot emit light, but still being gas it reflects but little light, and when it gets further from the nucleus it becomes condensed, and then as solid particles it is capable of reflecting light. The whole question of comets is one upon which no doubt great light will be thrown when a brilliant comet can be examined in the spectroscope.

I have now to pass for a few moments to an application of spectrum analysis in an entirely new direction. I stated that it was possible by means of this method of analysis to determine the motion of a luminous object in the line of sight; that it was possible by spectrum analysis to tell whether a star was coming towards the earth, or going from the earth; and also of determining approximately the velocity with which stars approach or recede from the earth. The importance of obtaining information upon this point will be obvious, when it is remembered that the so-called "proper motion of the stars" relates to that part of their true motion only which is at right angles with or transverse to the line of sight; because any motion that a star has in the line of sight directly towards the earth or from the earth would not cause any visible displacement in a star relatively to the stars near it; and therefore it could not be detected by the ordinary method of observation.

Now, I wish to endeavour to explain to you, in a few words, in what way it is that by spectrum analysis we may be able to determine the approach or recession of a luminous body. You all know, I think, that the colour of light depends upon the number of vibra

tions or impulses which reach the retina of the eye in a given time; just as the pitch of a note depends upon the number of pulsations of air which reach the ear in a given time. It is, therefore, obvious that if by any circumstance we can increase the number of impulses which fall upon the eye in a given time, say a second, then that light will no longer appear of the same colour. It is further obvious, that if a luminous body is coming near to us, or we are going towards it, that a greater number of these impulses will enter the eye in a second of time than would be the case if the luminous body and the observer were at rest relatively to each other. Just in the same way a swimmer striking out from the shore will pass through a greater number of waves in a given time than would wash upon his feet if he stood upon the shore; and each wave appears to him shorter, because he is passing through them, instead of allowing them merely to pass over his feet. Or if you imagine soldiers marching in single file, and that the distance between any two of the soldiers would represent the length of a wave of light, then it is obvious that if you are meeting the soldiers by walking in an opposite direction, you will pass a greater number of soldiers in a minute than you would do if you stood still and merely allowed them to pass you. Now, the velocity of light is so enormous that it is not possible for me to give you any experimental illustration of the change of colour produced in this way by the motion of a luminous body. If I could make a luminous body move at the rate of 20 miles, not in a minute, but in a second, that would be almost rest—it would be merely like a little snail crawling along a bank when the express train passes by—compared with the velocity of light. Even if I could make a luminous body move with a velocity of 120 miles in a second, the change of colour would be so exceedingly minute that it could not be seen by the eye; and it could only be detected in the spectroscope by showing that the light had shifted its position a little. It was the German physicist, Dopler, who, in 1841, first suggested that a change of colour might be produced in light in this way; he also suggested that a change of pitch or tone could be produced in sound in an analagous way. I dare say every one in this room is familiar—at least all those who have musical ears, which in the North of England means everybody—I suppose all of you will have noticed the change of pitch which occurs in a railway whistle. If you are standing in a railway station when an express train is approaching, the tone of the whistle will be very different after the train has past you, to what it was when approaching. I have here an apparatus by which I will endeavour to make this fact audible.

I can only hope the difference of pitch will be heard by those whose ears have been cultivated by musical education to discriminate minute differences of tone. I have at the top of this long rod an organ reed, which is connected by a tube with an air bag below, and when this air is allowed to pass through the tube, the reed will sound. While the reed is sounding I shall move this rod rapidly towards you and then as suddenly backwards, and I think you will notice that during the fraction of a second that it is approaching you the pitch of the reed will be higher; while during the fraction of a second that the reed is coming from you the tone of the reed will be lower. I hope the difference of tone is perceived. [The experiment was quite successful.] Nevertheless, it is true that, notwithstanding this, the colour of a star would not be altered though the star might be approaching or receding from us with great rapidity. Why? For this reason. The light of a star which we can perceive is not all the light that there is; that is to say, the stars send us impulses of force which the eye cannot perceive, because these impulses succeed each other too slowly, like sounds which are too bass for the ear to hear; and the stars also send us other waves of light of which the impulses succeed each other so rapidly that they are like sounds which are too shrill for the ear to catch. And if that part of the impulses from a star's light which the eye can perceive were moved either upwards or downwards in the spectrum, that is, towards the blue or towards the red, by the approach or recession of a star, then these invisible waves would be at the same time degraded or exalted into visibility, and would take the place of the light which had been shifted either upwards or downwards. Hence no change of colour would occur in the light of the star until the whole of these waves had been exalted or degraded into visibility, which would require a velocity far greater than could be conceived to take place in a star. In order, therefore, to apply this method of illustration to the stars, it was necessary that we should be able to pick out some one part of the star's light, and then be able to recognise that particular part of the star's light again in its altered position in the spectrum. Therefore it was not sufficient that we should be able to pick it out by its colour, because how should we know it again when it had changed its colour? But by means of spectrum analysis it can be done. We see in the spectrum of a star a bright line which we know to be coincident with the line in some terrestrial substance, say the line of hydrogen; then when once we find out that that line belongs to hydrogen, if it altered in the star, we can see exactly how much it has altered by comparing it

with the bright line of terrestrial hydrogen. The star which I found most suited to this method of investigation was the bright star Sirius. There will now be thrown upon the screen a representation of the spectrum of the star Sirius. I will explain the diagram. [There was first shown upon the screen a diagram of a part of the heavens, by Mr. Proctor, with the proper motion of each star marked with an arrow.] To each star is placed a small arrow, and the arrows represent the direction of the proper motion of these stars relatively to the motion of the earth. You will see that they are all up and down, in different directions. Now, if all these motions merely arose from the proper motion of the sun in space, then all these proper motions of the stars would be in one direction; but you see they are in different directions. This shows the great importance of obtaining information of that part of their motion which is either towards or from the earth. I will now pass to the star Sirius, upon which the experiment was made. This star is remarkable for having in its spectrum three very strong lines, which have been found to be coincident with hydrogen—one in the blue, one in the green, and one in the red. It is necessary to say how it is that one knows that these lines are coincident with hydrogen. These lines were compared directly with the bright lines of hydrogen; and, in a spectroscope of considerable power, these lines appeared to be exactly coincident with the lines of hydrogen. But when a very powerful spectroscope was obtained, it was found that this green line, which was the only one which was bright enough to allow examination to be made, that this bright line was not absolutely coincident with the line of hydrogen, the probability therefore was that it had been slowly moved by the motion of the star. In the next view we shall have the comparison of this line with the line of hydrogen. Now you see that this bright line in Sirius is not exactly in the position of the one in the solar spectrum and in the spectrum of hydrogen. Then it might be said that this broader line had expanded in one direction rather than in the other, and that this was no proof that the line had actually been displaced by the movement of the stars. Now you will see above the upper spectrum a faint haze of light just in the position of the bright line of rarefied hydrogen, that represents the appearance which the same line has when hydrogen is subject to a pressure of air around us. The line being broad in Sirius showed that the hydrogen there is of rather greater density than it is in the sun, or than it was in this rarefied gas. I then made a series of experiments by which I found that

as this narrow line is converted into this broad line, by alteration in pressure of the hydrogen, it rose symmetrically—that is, equally on both sides; therefore we had a right to say that the want of coincidence really indicated that the line of the star had been shifted to a small degree by the motion of the star. The next point, therefore, was to determine what velocity in the star would be required to cause this. It was found that about 40 miles in a second would be required. But at that time the earth was moving in its orbit from the star with a velocity of about 11 miles per second, leaving, therefore, 29 miles per second as indicating the velocity of the recession of the star. There would also have to be deducted about four miles per second, due to the motion of the sun, leaving about 25 miles per second as the rate of the recession of the star from us. It had been found before, by ordinary observation, that the motion of a star at right angles to the line of sight was from 30 to 35 miles per second. The true motion of a star would therefore be compounded of these two parts. At present this method has not been applied to any of the other stars, for it involves extreme difficulty, a very fine state of the atmosphere, and powerful instruments. I hope that after a time we shall be able to apply it to other stars.

I will now just, in conclusion, for a few moments, as I have not time to go into it properly, show the application of this method to the visibility of the red flames about the sun at the time of a solar eclipse. You have now upon the scene a representation of a solar eclipse, one of the grandest phenomena of nature. At such a time we discover that the sun, as viewed by us on ordinary occasions, is not the whole of that body, that there is something more about the sun than we see.

At the time of an eclipse the moon covers the sun, and at the time this picture was taken, the moon appeared a little larger than the sun, which was overlapped and entirely concealed but there were visible at the bottom and at the top, large red flames, consisting of great columns of luminous hydrogen, extending in one case to a distance of 80,000 miles from the sun. Now why is it that these appearances can be seen only at the time of a solar eclipse? They are not rendered invisible by the glare of the sun itself; for it would be possible to hold a screen between the eye and the sun, and so make a sort of temporary eclipse. They are prevented from being seen in consequence of the imperfect transparency of our atmosphere, for our atmosphere scatters a large quantity of the light that comes upon it. You always notice that the sky is very bright close to the sun. Now

the light scattered from our atmosphere is greater than the light of these appendages of the sun. Our atmosphere forms a bright screen, which conceals them; but at the time of a solar eclipse the light is cut off by the moon on the other side of our atmosphere, and no light falls upon our atmosphere, which is not illuminated, and then it is that these objects become visible. Mr. Lockyer first published a suggestion that by spectrum analysi these objects might possibly be examined; and the same idea occurred also, quite independently, about the same time to Mr. Stone, of Greenwich, and to myself. However, from various causes, the experiments made at that time were not successful. The principle upon which the conjecture was based is this—it seemed probable, especially from the speculations of Mr. Stoney—that these flames consisted of gas. Now, if they consisted of gas, they would give a spectrum of bright lines. But the light coming to us from our atmosphere was reflected solar light, and we know that solar light consists of all colours; therefore, if we applied the spectroscope, the prism would spread out the light from the atmosphere and diminish it perhaps a hundredfold; while if the light of the prominences consisted of bright lines, it would only separate that light into bright lines, and each line would be perhaps only one-third or one-fourth as bright as the prominences; while the light of our atmosphere, or what is the same thing, that part of the light, of the same colour as the lines of the prominences, would be reduced perhaps one hundred fold; and in this way we should diminish the brightness of the interposed air in a much greater degree than we should diminish the brightness of the objects which lie beyond it. This method was applied at the eclipse of 1858 in India, and it was found during the eclipse that these prominences gave bright lines. The next day Mr. Janssen applied the spectroscope to the edge of the sun, and saw the lines of these objects distinctly in the full glare of the sun. About a month later Mr. Lockyer, having a more powerful spectroscope, also succeeded; and others when they have looked at the sun with a knowledge of the position of these lines were able at once to see them. Mr. Lockyer has since investigated these lines with very great success, and it is found that at certain times these prominences, these masses of gas about the sun, contain other substances besides hydrogen, the vapours of substances which we know to be present in the sun, such as iron, magnesium, and sodium. It was also found that these gases shoot up at certain times in the form of circular storms, with the gases whirling around at the same time that they are shooting

upwards. However, up to this time the form of these objects had not been seen directly, only the bright lines of their spectra, and the forms of them were inferred by causing the slit to traverse over these objects, and then, by noticing the different lengths of the line, as the slit went over the different parts of the prominences, to guess at the forms of the objects. The diagram represents the bright lines of these prominences compared with the lines of hydrogen. Those are the bright lines which are almost always seen in these masses of gas about the sun, but at certain times other lines are also present. I was saying that the form of these objects had not been seen. After several trials I succeeded, by means of a wide slit, in being able to see directly the shape of one of these objects; and you now have upon the screen the representation of the first of these objects ever seen directly, excepting at the time of a solar eclipse. This method of reviewing the forms of these objects has been applied very successfully abroad by Zöllner, in Germany, and by Respighi, in Italy. You have here a representation of these objects as seen at intervals of a few months, by Zöllner, showing how rapidly they change. The first has the appearance of a short tree; in a quarter of an hour it had shot up into a long peak. At the same time that many of these objects changed thus in a few minutes, others seemed to be very persistent for some days. The Italian observer, Respighi, has mapped these objects, and placed them as they appear on successive days under the other, so as to compare the appearances of these flames at different times. Besides these objects to which I have referred, at the time of a solar eclipse there is also seen about the sun a large mass of light, which has been called the "corona." And this apparently consists of two portions, the light immediately about the sun and those large beams which are sometimes seen to extend outward in different directions. The question has long agitated astronomers as to the nature of these appearances. Is it the result of some luminous atmosphere about the sun—some atmosphere exterior to the atmosphere of hydrogen? Is it some meteoric matter revolving round the sun? or is it caused by anything about the moon or in our own atmosphere? The more observations have been made upon these objects the more puzzling the phenomena appear, and the less light seems to be thrown upon them. During the eclipse in India in 1868 this light was carefully observed by the polariscope, to show whether the light was original or reflected. By this instrument observers were enabled to show that the light of the corona was not original light, but that it was reflected light, and that it was the sun's light

reflected from something. But at the total eclipse of the sun which occurred in America last year, a quite different account was given. There it was stated that this light, for the most part at least, was not reflected, but that it was self-originated light, and that it gave not a continuous spectrum, but one in which bright lines appeared. Then again there is the extraordinary circumstance that these outer portions of the corona have not been seen by different observers in exactly the same position. It is therefore doubtful how far these outer beams are realities, or whether they may not be optical phenomena. The investigation of this coronal is the great object to be attempted at the approaching eclipse. A large number of observers are going out to Spain and Sicily, where it will be visible, for the purpose especially of endeavouring to obtain a knowledge of what the corona is. Our own countrymen, unfortunately, will not be able to take so good a share in this work as we had hoped. Application was made to the government by the scientific bodies as far back as June last for a ship and assistance to go out; but we received from Mr. Childers a flat refusal to give a ship, and in consequence great delay has occurred. However, at last the government have agreed to assist us, and I am happy to say that they have now granted a ship to go to Spain, and a sum of money not exceeding £2,000 to assist observers to go to Sicily, and for providing apparatus; but it will now be scarcely possible to provide the apparatus, or to organise the expedition as might have been done at an earlier time. We can, without grudge or envy, I think, share in the delight of our American friends who have been exceedingly energetic in this matter. It seems that they concluded that we should immediately get the aid from our govern ment that we asked for, and they applied to their government, and at once a vote of £6,000 was made to send a thoroughly equipped expedition all across the Atlantic, in order to observe the eclipse in Spain and Sicily. I recently had the pleasure of meeting several of these American astronomers. No doubt a good many of our countrymen will still go out, and it is not improbable that from some one you may hear of the results of the expedition; and I hope that then we shall get some light as to the true nature of this mysterious corona.

ON COAL.

A LECTURE

BY

W. BOYD DAWKINS, ESQ., M.A., F.R.S., F.G.S.,

Delivered in the Hulme Town Hall, Manchester, November 22, 1870.

I THINK that we who live in Manchester have an especial right to know what coal is. The very fact that Manchester stands where it is, and the very fact that we are living in a city of over 500,000 souls, instead of in a little village, is simply owing to the circumstance of coal being found here. Coal is the great centre of our prosperity, and upon it depends nearly all the success of our manufacturing enterprise. The political economist will tell you that upon it the future of England mainly depends. When it is exhausted, then we shall have to look forward to the condition of things which now obtains in those regions where there is no coal. That is to say, instead of our being a nation full of manufacturing and mercantile enterprise, a great nation to which all the people of the earth resort, we shall be merely a people who live for ourselves by the cultivation of the ground. The duration of our coal fields, the length of time for which we have a supply of coal, has been ascertained within certain limits. Mr. Hull, an accomplished geologist, one of the geological surveyors, tells us that in England at the present time, we have a stock of coal sufficient for our consumption for no less than 1,000 years. On the other hand, Professor Jevons, whose opinion is worthy of the very greatest weight on such questions, calculates that 100 years is about the

tenure of our coal fields, according to the present rate of the increase in the consumption. Whether we take the limit of 100 or 1,000 years, the end is perfectly inevitable. Sooner or later, whether you take the sooner by the century or the later by ten centuries, the end ultimately must come when the coal will be exhausted, when the great mainspring of our commercial enterprise will be gone, and we shall revert to that condition in which we were before the coal fields were worked. In this point of view, therefore, coal has a particular interest for us. But this is not the point of view which I intend to speak upon this evening. If coal is important in this direction, it is no less important in a purely scientific point of view, apart from any mercantile aim or end.

The physicist will tell you the wondrous story, that the black substance which you burn is simply so much light and heat and motion borrowed from the sun and invested in the tissues of plants. He will tell you that when you sit round your firesides, the flame which enlivens you, and the gas which enables you to read, and which civilises you, is nothing in the world but so much sunlight and so much sun heat bottled up in the tissues of vegetables, and simply reproduced in your grates and gas-burners. Very few persons, I am afraid, realise this, which is one of the many stories which science in its higher teachings shows us—one of those fairy tales which are the result of the most careful scientific investigation. I cannot enter into this aspect of the question this evening. My object is to give you an intelligible idea of some of the forms of life which are locked up in the coal; and I wish to show how the coal came to be what it is, for we cannot in this case take refuge in the answer which Topsy gave, we cannot suppose that it "grew," and nothing else. In this quesion of how it came to be what it is, there are geological issues of much higher importance than those which are merely wrapped up in coal, and which bear upon the structure of our globe, and upon the constitution of the earth in general.

Now, to begin at the beginning, we will make our start from the coal scuttle. I suppose we all of us know what a lump of coal is. It is a body more or less hard, and you will find that it is readily divisible into two very distinct portions. First of all you will find that the portion of coal which gives the greatest flame is hard, shining, and brittle; that is to say, it contains a large quantity of bitumen. But besides that there is another part of nearly every piece of coal which is of a dull black colour and friable, and resolvable more or less into layers. That dull portion consists of fossilised wood or

mineral charcoal; how it has taken that form of charcoal I am going to show you presently. We may take two species of this combustible material as the exponents of these two distinct portions. First of all, for the bituminous, we may take the cannel coal, that valuable seam at Wigan, as representing the maximum of bituminous matter which occurs in coal. On the other hand we may take the dull stony looking material—which is becoming more and more important every day for smelting iron and like purposes—the anthracite coal, as the exponent of the mineral or charcoal element. But although I am speaking of these two classes as if they were distinct from each other, yet, in fact, we find that the one shades off into the other without any perceptible boundary line between them. For instance, in the Forest of Dean you will find a seam of coal which in its upper portion nearest the surface is bituminous, that is to say, flame-giving; while as it goes deeper it gradually loses these properties and takes the form of the anthracite.

The chemist will tell you the chemical difference between these two kinds of coal; and in this diagram I have represented the relation which the wood, peat, and coal bear to the anthracite. You will see that in going down from wood to peat the percentage of carbon increases; and in going from peat to coal the percentage of carbon increases, until at anthracite you have the greatest percentage of carbon. The whole difference between anthracite coal and ordinary coal consists in this, that the bituminous portion of the anthracite has been removed in some way; while in the case of ordinary coal the hydrogen and oxygen of the bituminous part still remain.

We will first concentrate our attention upon the bituminous element. If you take a piece of ordinary coal and reduce it sufficiently thin to be transparent, you will see the material out of which it is made. In nine cases out of ten this is the sort of thing you will see. Supposing this black board to represent a slice of coal, these lines which I am drawing upon it will show what you would see under the microscope. First, you will notice that the dark material consists of a series of minute bodies more or less rounded, which lie over and interlace with one another, and make up the main substance of the coal. But besides that you will notice other substances more or less round, very much larger, and resembling small bags pressed flat (Figs. 1, 2). Some of these larger rounded bodies which we find in coal are found to contain these smaller rounded bodies of which the main mass of bituminous coal consists. Both are made up more or less of

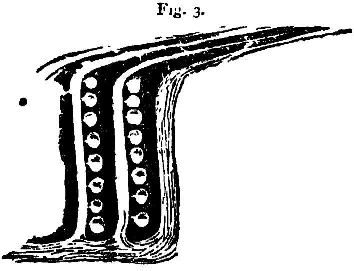
Figs. 1 and 2.

Spore-cases of Flemingites gracilis × 5.—CARRUTHERS.

pure bitumen; and there can be no doubt that the bituminous nature of coal depends upon the amount of matter which is furnished to the coal by either this larger body, or this smaller rounded body. The question therefore for us is—What are these bituminous bodies? Fortunately, through the labours, first of Professor Morris and secondly of Mr. Carruthers, and last, though not least, of Professor Huxley, I am able to tell you what these bituminous materials consist of.

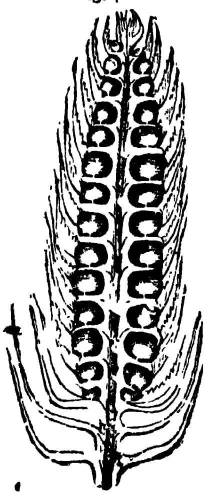
Professor Morris has demonstrated that these little bodies which lie inside the others are nothing more than minute spores or seeds, and that the larger bodies, which I drew upon the board, consist of the cases in which these spores were contained. Fortunately, also, Mr. Carruthers has been able to show us the sort of fruit which produced these sporangia, or seed cases, and the little spores which I have drawn upon the board. He has shown us that all these bodies are derived from a cone of this particular sort (Fig. 3):—First of all you get an axis of woody matter, then you get a series of leaves running up on each side, and in, between these, the little spore cases lie crowded together like soldiers in double file. Each of these little bags is found to be full of spores; and so the cone is built up until the whole resembles more the form of a fir cone than any other which is familiar to us. This form of vegetation has been termed by Mr. Carruthers "Flemingites," after Dr. Fleming. Now as Mr. Carruthers is able to trace up these spores into their spore cases, and into the fruit which produces them, can we not trace them still further into some analogy with a living order of vegetation? I think that that is not at all difficult. There is a certain low form of vegetation which we find inhabiting some of our higher mountains in England, and which we find spread more or less throughout the world, and that is the form which we term the "club moss." The little club moss which grows so freely in Scotland and on the Alps bears precisely the same kind of fruit as that of which the coal is made up. I have in that diagram drawn one of the fruits of the lycopodium,

Fig. 3.



Section of portion of Cone of *Flemingites gracilis*—nat. size—CARRUTHERS.

Fig. 4

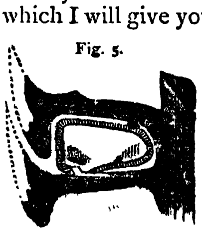


Section of Cone of *Lycopodium Cernuum.*—CARS.

or club moss (Fig. 4). Here you see a portion of the cone. Each cone in the club moss gradually rises from a branch until the end is terminated as you see it there. Outside you find a series of scales or leaves, and inside them and fixed upon each you will find one of these spore cases or bags full of little spores. Those little spores I have represented here, and if you compare these with the spores which Professor Huxley has found in his bituminous coal, I think you would be very clever indeed if you could detect any essential difference. There can be no doubt that the bituminous matter of coal is derived nearly altogether from the decomposition of the spores and the sporangia of fossil vegetables closely allied to the club moss. And if we come to examine what the character of spores of the club moss is, we can easily understand how the bituminous material in coal is derived from like objects. At the present day, these are so full of resinous matter that they are used for making fireworks, on the continent, instead of sulphur, and because they are not readily affected by water—they are used by the apothecaries for coating pills. Our bituminous coal derives its bitumen from this altered resinous matter, which was first of all stored up in fruits of that kind, and afterwards altered by the subterranean heat into bitumen, thus forming our bituminous or blazing coals.

But this little vegetable is not the only form which we have to deal with in the coal measures. We have another very remarkable form, closely allied to the club moss—we have the lepidodendron, of which I will give you a figure presently. Those little spores, of which

Fig. 5.



Section of part of Cone of Lepidodendron (*Lepidostrobus*)—HOOKER.

I have been speaking, are found not merely in Flemingites, they are also found in some other analogous forms. We find them first of all in the cone which I have represented here (Fig. 5); compare that with the diagram (Fig. 6), and you will find scarcely any appreciable difference between the forms of the two cones—the recent lycopodium, or club moss, and the ancient fossil club moss, lepidodendron. These are (Fig. 6) two of the

spores contained in the spore-case of fig. 5 which contribute to the formation of bituminous coal. Can we not make out something as to the form of vegetation by which that particular cone was supported? Fortunately we can. On that screen I have represented, on the right hand side, two small branches, bearing leaves which are scarcely separable in kind from those of the common club moss; and on the other side I have represented a large fragment of the trunk with the branches standing on it, which has been found near Newcastle, and which is not less than three feet in diameter, and forty-nine feet high. That was the stature of the club moss of the carboniferous period. If we compare that with the stature of the club moss of the present day we shall be very much astonished. The great majority of the living club mosses are not much longer than your finger, and the largest of them is not more than six feet high.

Fig. 6.

Spores of *Lepidostrobus* highly magnified--HKR.

If we pass now to the microscopic structure of this wonderful carboniferous plant, I think we cannot help admiring its complexity. In this diagram you see a microscopic section of one of these bodies which supported the coal, and which forms part of the cone. In the interior you will see rather an obscure mass, which consists of a series of vessels; then outside that there is a layer of vessels which are more compact; then outside that again there is a layer, which is more or less broken up, of what is called "cellular tissue;" outside that again you will find a layer which corresponds to the bark of our trees. You will notice that here and there in that outer layer there are certain light areas. Those light areas represent the small spaces in which originally there were small bundles of fibres leading from the very interior of that body right away to the outside, to support small leaves, which more resembled the leaves of our fir trees than any of which we have knowledge. This is a photograph of a beautiful drawing which was made by Mr. Binney. In this next section I show you the real original thing. That is a section which has been cut so thin that the light passes through it, and you can see very much the same arrangement as you saw in the photograph. You can see the inner mass of vascular fibre, and you can see the next layer of rather thinner cellular material; and outside you can see the arrangement of the bark. Unfortunately, although we are able to make out the fruit and the leaves and the stem of this most wonderful tree, we know nothing of its roots.

But besides this form of vegetation, many others contribute their substance to the formation of coal. This diagram represents

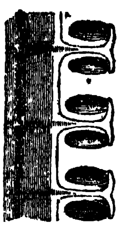
a ulodendron, and those things that look like scales, and which have originally given support to leaves, are arranged in the tesselated way which characterises the lycopods, ferns, and the fir tribe. All we can say is, that it is one of the club moss tribe; and those large rounded scars which you see are merely the portions from which branches have grown. Of this form of vegetation we know next to nothing. I have brought it before you simply because it is very beautiful and very characteristic of the coal measures.

And now I must pass on to another form of vegetable life to which the coal owes a large part of its anthracitic or mineral charcoal character. This diagram represents the appearance of sigillaria, so called because each of these little points of light roughly represents the impression of a seal, and between each you will see going more or less straight down a bright line. Each of these little points supported a leaf; but the form of that leaf we do not know. A great number of fossils presenting that pattern have been found, and the most remarkable of them I shall represent to you in the next diagram. There you see a large trunk. A trunk of that kind has been found no less than seven feet high and fifteen feet in circumference. And this trunk has been found attached to a root of a very different pattern. In that root the little points are arranged in a different way, more like those of the lepidodendron. So different were these patterns the one from the other, that originally botanists were agreed that this root of sigillaria, or stigmaria as it was termed, was altogether a different thing from the trunk which it supports; but fortunately Mr. Prestwich and Mr. Binney have both proved that this great trunk really belonged to the stigmarian root. It was composed, very much like one of our forest trees, of woody fibre. But in all the cases in which we find it in our coal measures in Lancashire and elsewhere, the woody fibre is gone, and those impressions which you see are merely the impressions of the bark. Nor need we wonder that the bark should remain while the woody fibre should perish; for if we go into any tropical forest, we shall find that the woody fibre decays very much faster than the bark; so that the trunk of a fallen tree that appears perfectly sound to the eye is speedily reduced to an empty cylinder of bark. In nine cases out of ten the woody fibre disappears in tropical forests in two or three years, and nothing is left but a shell of bark. That is very much what has happened in our coal measures. These upright trunks have originally been reduced to a thin layer of bark; and the hollow within has been filled with sandstone or shale, or whatever happened

to be on the top of the layer of coal. In working coal mines one great source of danger to the miner arises from the fact that the pillar of stone which is consolidated in the space once occupied by the hard wood is merely kept up above the seam of coal by the cohesion of the fossilised bark. When that thin layer decomposes, down come these "stools," as they are termed, and very often cause the death of the man who is working underneath them. The fruit of the sigillaria is unknown. Dr. Hooker has suggested that very possibly this form of vegetation may have been allied to the tree ferns. But if we are uncertain about the top of this tree, we can by no means be uncertain as regards the roots, which penetrate nearly everywhere throughout the coal measures, and in certain layers underneath the coal these roots are omnipresent. This is a microscopic section of a nodule from a layer of coal in which these roots occur, and you will see on the right hand side one of these rootlets find their way into nearly all the vegetable organisms which occur in the coal.

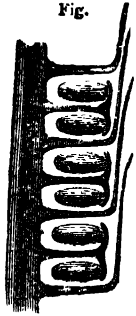
Another kind of plant contributed its tissues and spores largely to the formation of coal. There are certain bodies with which we are all more or less familiar, which are known by the name of "calamites," because they resemble more or less a reed. Each is divided into a series of segments, and these segments are connected together by a series of lines, and this is what we are familiar with under the name of "calamites." It is merely the cast of the interior of the stem of a plant. According to Mr. Carruthers, the foliage was arranged in whorls, and the apex of each branch bore a kind of cone. This calamite is closely allied to the common *equisetum*, or "mare's tail," which lives in our marshes. If we compare the fruit of the mare's tail with those of this ancient carboniferous vegetable, the only difference that we can detect is one of very small value. We get in the common mare's tail (Fig. 7) a cone, and on each side of the axis of this cone a series of leaflets is given off; and inside each of these little leaflets, above and below, we get the sporangium. In the calamite, on the other hand, we get this difference—we have the same arrangement of the sporangia; they lie inside a leaflet of that kind, but they are covered over by another leaflet (Fig. 8). The fact of the fructification of the calamite being covered by a leaflet is the only fact to my mind which separates the fructification of the calamite from that of the common

Fig. 7.



Section of portion of fruit of Equisetum —CARRUTHERS.

Fig.



Section of part of fruit of Calamites (*Volkmannia Binneyi*) —CARS.

mare's tail of our marshes. If we refer to the microscopic texture, on the other hand, we shall find very considerable differences. In the common mare's tail we have no arrangement of woody fibre of that kind. This is a section of a calamite, and at the very edge you will see little wedges of woody fibre radiating from each of those bright points; while on the inside there is a mass of cellular tissue —that is tissue made up of cells. This represents a young plant, but as it gets older the internal cellular tissue disappears, and what you get is a series of woody wedges which take that particular form. What you find so common by fossils is merely the cast of that cylinder with all the woody fibre gone.

Besides these forms of vegetation there were many others in the coal measures, such as pines, which you can scarcely distinguish from those which are now living. In that section I have represented one of those rare ferns in the coal measures in which the fructification—the little spore-cases at the back of the leaves—is preserved. That is a very rare case, and the reason of that I will tell you presently. Besides these common sorts, we have evidence that there were tree ferns. Here you have a picture which represents the vegetation of the period when the coal was formed. In those trees in the centre you see the fossil club moss. In those which rest close to the water you can gather an idea of the foliage which the calamites presented, the equiseta of those days. The equisetum of the present day is seldom more than a foot high; in the coal measures it is more than twenty feet high. There you see the lepidodenrdon and the pine; and in those trunks lying prostrate, and those ferns, you can gather a very adequate notion of the conditions under which the carboniferous vegetation lived.

But we have no reason for believing that this was the only vegetation living at that time, because Dr. Lindley, the eminent botanist, has found out, by actual experiment, that different vegetables have different powers of resisting decay. After an immersion in water of rather more than two years, all the mosses had disappeared, and all the higher organised woody trees, those which are familiar to us in our forests, such as the oak and the ash, had gone with the exception of the pines, which are found in our coal. The grasses and the sedges had also disappeared; but the ferns were well preserved, as well as the arborescent forms, the tree ferns

and the lycopodia or club mosses. So that the fact of our finding the ferns and the calamites, and the trees of the club moss kind more or less well preserved in the coal, does not at all lead to our believing that those were the only forms of vegetable life in the ancient forests of the carboniferous period. Were a tropical forest of the present day exposed to the same vicissitudes as those from which coal is formed, it would not present higher forms of vegetation. It is worthy of note, that in Dr. Lindley's experiment, all the ferns had lost their fructification—a fact which explains why it is so rarely found in those of the coal measures.

To sum up the evidence as to the origin of coal—just as the bituminous portion owes its bitumen to the resin stored up in the seed vessels of vegetables allied to the lycopodia, and possibly also to those of the ferns, so is the anthracite made up of the tissue of various plants, more or less decomposed; and both kinds have been profoundly modified by the action of the internal heat of the earth.

I have now to pass on to the conditions under which the vegetable matter was accumulated. We find under each bed of coal a layer of "under clay," as it is termed, that is as full of the rootlets of sigillaria as it well can be. It is therefore clear, that it was the soil on which the vegetation grew. In some cases we can prove that the roots and rootlets penetrated the bed of coal, very much in the same way that the roots of trees now penetrate the soil. Therefore, there can be no doubt that the under clay which you find below every seam of coal is the soil on which the trees grew; and that the layer of coal above, which is sometimes equally penetrated with roots, is the accumulation of vegetable matter on that soil. That is a very important point, because it leads us to an adequate idea of the conditions under which the coal was formed. It proves that these ancient forms of vegetation were laid up in the form of coal very much where they grew. There is evidence also that these forms grew not very far from high-water mark. In the first place, the layers of coal run more or less straight, like the modern alluvia, though they are broken up here and there from causes of which I shall speak presently. If you could strip off from some particular layer of coal the superincumbent rocks with which it is overlaid, then you would frequently find the channels formed by water while the coal was being formed. Supposing we take this black board to represent a portion of the 4-foot coal in the Forest of Dean, there we get ramifying through this layer of coal a series of channels filled with sandstone and shale. Now, there can be no doubt, that in this particular instance, the reason why we have stone instead of

coal, is simply owing to the fact that in the old days streams of water played upon the vegetable matter, and these streams wore it away into channels, and these channels have been filled up with sand and shale. Such a series you may find at the mouth of any river you chose to examine. At Fleetwood you will find, hollowed out in the soft mud, a series of channels of that kind; and if the sea should come over and deposit sand, then you would find those mud channels filled with sand, just in the same way as in the coal measures of the Forest of Dean. We have also clear evidence that the coal was not accumulated under water, in the simple fact that the small spores, of which the bituminous coal is made up, are so light that they would float on the surface, and could not possibly become waterlogged. We can therefore gather this idea relative to the accumulation of coal—that the coal accumulated where the vegetation grew, and that the place where the vegetation grew was not far from high-water mark. Besides that particular evidence, we have the evidence of sundry other fossils which are found associated with the coal. We find terrestrial creatures, such as scorpions, which are not readily distinguishable from those living at the present day. We find beetles; and in one remarkable case which Dr. Dawson investigated in Canada, a large trunk of sigillaria was found which was filled with sandstone. Sir Charles Lyell suggested, that as this trunk was standing upright, it was extremely probable that in the old days it was the hollow stump of a tree, and that it was probable that in the old carboniferous days, as at present, the hollow trunks of trees formed a trap for small creatures to fall into and die. So Dr. Dawson investigated, bit by bit, the contents of this fossil hollow trunk, and he found a small worm which is scarcely to be distinguished from a living centipede; he found a small land shell which is not very far removed from a modern pupa. Those two forms of life in that trunk of sigillaria testify to the fact that the coal was accumulated on the land, and not in the sea.

There are many other forms of life in the coal. We have large creatures of the reptilian kind, allied, more or less, to our frogs and newts. This is the representation of the skull of an archegesaurus, which was found in Germany, and that lower jaw belongs to the Proteus, which is one of the amphibians, resembling a newt. If you compare the lower jaw of those two animals, you cannot fail to detect a considerable resemblance.

Apart from its surroundings, I have hitherto spoken of coal itself. It is always associated with sandstone and shales,

which are indisputably derived from the wear and tear of the land by water. The first difficulty that strikes us in regard to the formation of a bed of coal is—how is it that while it is associated with sandstone and shale and clay, it is so purely vegetable? If we refer to the great cyprus swamps on the banks of the Mississippi we shall easily gather a reason for that. There we find large quantities of peaty matter accumulating, and that peaty matter is more or less enveloped in the floods every spring; but those floods of the Mississippi lose all their sand and mud long before they arrive at the peaty matter in the middle. Round those swamps there is a fringe of rushes and mosses which completely strains off all earthy and sandy material, and the result is that in the interior you get a perfectly pure vegetable matter very much like that of which our coal is composed. I have no doubt whatever that the purity of our coal is in part owing to the earthy matter being strained off by these grasses, sedges, and rushes, which subsequently disappeared by that action to which Dr. Lindley has called our attention. It is, however, easily explained by the simple fact that the vegetation accumulated where it grew. Indeed these old coal layers call to mind our peat bogs. We find a layer of peat nearly everywhere on our coast line between high and low water mark, — at Fleetwood, for instance, — which is perfectly pure and free from extraneous matter; although it is based upon a layer of clay and is covered by marine sand. Each layer of coal represents a mass of vegetable matter accumulated on the ancient land surface, just like that of the Lancashire coast, while the sandstones and shales were deposited by water on the submerged lands, and each of the many layers of coal represents a new submergence. This, of course, presupposes that change of level has taken place; and to show you that it is not unreasonable to suppose that in the carboniferous epoch changes of level did take place, I may adduce one or two instances which have taken place, during this century. In the valley of the Mississippi, in 1812, an earthquake took place, and a large area of country in which the cypress trees grew was sunk beneath the level of the water; and the stumps of cypress trees and the peat were completely covered up with alluvium, very much as any seam of coal might be now-a-days. In India, in 1819, a large alluvial plain was suddenly submerged by an earthquake, in the Gulf of Cutch, and a solitary fort was left which marked the extent of the depression. Like causes produced like effects in the coal measures.

The next question for us to discuss is—how these changes of

level are brought about; and that is not at all hard to answer. They are caused altogether by the internal heat of the earth. I dare say that many of you know that in the mines the deeper you go the hotter the atmosphere becomes. Speaking roughly, the increase of temperature in going down into any part of the earth's crust is one degree for 65 feet of descent. Sir C. Lyell has estimated that at a depth of two miles we should arrive at the temperature of boiling water, and at a depth of 34 miles we should arrive at the temperature of molten iron. This heat manifests itself in the hot springs which we find at Bath and other places, and in volcanos; and it is this internal heat which has caused the depressions of the land on which the coal was accumulated.

You know that if you heat a poker, it expands; the heat making it longer. The earth is in the same state as a hot poker, and parts of it expand or contract as the heat within it ebbs and flows. I have here a section of the coal measures of Lancashire. Upon a thick base of millstone grit, of which most of our hills are composed, you have the coal-producing rocks, which, instead of being horizontal, as they were originally, have been tilted up by the unequal expansion and contraction of heated rock within the earth. If the heat ebb away from one portion, the land above will be depressed, if it flow towards it it will rise. In this way all the changes of level can be explained. This subterranean heat is the cause of another phenomenon. You know that in the coal measures we have what are termed "faults;" that is, every now and then you have a break in the seams or strata. Those experienced in mining know that in tracing this break, if it goes over the miner's head, he has to sink down in order to regain the seam of coal. On the other hand, if a "fault" or "break" goes under your feet (for these faults are hardly ever vertical), then you have to go up. Now the result of this arrangement is, that the rocks are divided into a series of wedges, and these wedges are directly traceable to the exertion of the same heat which caused the tilting up of the rocks. Mr. Hopkins has shown that there are continual movements of heat in the earth, sometimes in one direction and sometimes in another. He has also shown that when the internal heat of the earth causes the matter to expand, the solid crust above must be divided into a series of wedges; and that it follows naturally that the wedges which have their broad ends at the bottom must be thrust up higher than those with their narrow ends downwards. As the heated matter expands, the triangles with the bases below are thrust upwards, while the others will be left very much as they were. In that way we can

account for the almost invariable position which these "faults" take in the rocks; and we can understand how it is that the miner finds the fault above his head when the seam he wishes to find is below him, and when the fault is beneath him he looks for the seam of coal above. Thus we can ascribe faults and disturbances in the rocks and changes of level to the internal heat of the earth.

You will naturally ask,—How long ago is it since the coal was formed? I am extremely sorry that I cannot tell you. It is so long ago that we cannot grasp the idea of the lapse of time. Here, in the Manchester coal field, we have no less than 6,800 feet of deposit, and in it we have no less than sixty feet of workable coal. But the Lancashire coal field is not the thickest. There are coal fields in the Forest of Dean and in America, which are much larger and much thicker. The coal fields must have demanded a vast amount of time for their accumulation; and the carboniferous epoch is separated from us by an interval too great to be bridged over by any unit of time which can be devised.

In conclusion, I thank you for the patience with which you have listened to what I have said this evening about the very difficult subject of the natural history of coal. It is a mere scrap of the record of time past, which all of you can read for yourselves in the rocks if you care to take the trouble. If I can send any of you away with one new idea relative to coal I shall have gained my end. I think I ought not to let you go away without mentioning an example which each of you in this room may follow. There are two working men in Oldham who have not better opportunities than any of us here of working at geology, or at anything else out of their own daily mill work. These two men, Mr. Butterworth and Mr. Whittaker, by name, have collected together a large portion of the matter which I was enabled to bring before you this evening. They have simply done this by using that common sense which all of you must possess, and which all of you can apply, if you only care to look outside yourselves, and to look into nature, and to see what wonders and what mysteries there are lying at your very doors. I am quite sure that none of you would be at all the less happy, but far more happy for any study whatever that would take you out of your own ruts of life, so to speak, and show you what beautiful things there are in nature. I sincerely hope that one of the outcomes of this set of lectures will be, that for some of you life will be the sweeter—that some of you will realise that knowledge is better than riches.

CHARLES DICKENS.

A LECTURE

BY

PROFESSOR WARD

Delivered in the Hulme Town Hall, Manchester, Nov. 30, 1870.

YOU will, I hope, believe me when I say that I feel half sorry and half glad to have undertaken to speak to you to-night about Charles Dickens: sorry, because I cannot quite suppress a fear lest it may seem presumptuous in one whose name must be strange to nearly all his hearers to address them concerning one whose name is familiar on all their lips; glad, because I feel assured that any attempt to do honour to a great memory must have something in it to commend itself to your sympathies at the very outset. For, indeed, I have no claims to discuss the subject which I have proposed for our consideration but two, and these two of very different value: the one, that there is in this room no more cordial admirer of the genius of the late Mr. Dickens than myself; the other, that my own studies have lain so much among writers of the past, among the works of the few whose fame is still green in the nation which they adorned, and the many whose reputation is to all intents and purposes (like Old Marley in the *Christmas Carol*) as dead as a door-nail, that I often ask myself the question, What is it in the works of the former which ensures to them the highest reward of literary effort—a lasting national popularity? Such an enquiry I will venture to-night to make with regard to the works of one of the most popular writers—probably the most popular writer—of our own generation. And this enquiry, if conducted with something of care, will not, I hope, be wholly without profit. Literary criticism has its uses as well as its

abuses; but there is no cause to shrink from it as a vain expenditure of time. To know the reason why we admire, is a very different thing from studying with a determination not to admire at all. And you will allow me to say that I should not have dared to follow on this platform men who have spoken to you as masters of the sciences with which they have dealt, if I were not convinced that the criticism of a great writer is as worthy an occupation for the mind, and one as capable of being conducted on true principles, and according to a rational method, as scientific enquiry into the wonderful phenomena of physics. I cannot speak with authority, like my predecessors; but I can address myself to my task with as full a consciousness of its importance as that which animates them with regard to theirs.

I shall endeavour, then to make good this assertion: that the name of Dickens is destined to endure, and that the glorious hope which inspired his lifelong labours was not a delusion.

For, that such a hope inspired him, I can make no doubt whatever. The fame which he sought was not the mere favour of the day, which brings applause and gold; the art to which he devoted himself was not one which desires to be crowned only with wreaths doomed to wither on the morrow of the festival. On the last—the very last—occasion when Mr. Dickens spoke in public, the fact that he and those around him were mourning the loss of a distinguished fellow-artist, and he in particular a dear personal friend, gave to his words a tone of melancholy usually foreign to them. But, as if he had known that he was never again to open his lips before an assemblage of his fellow-countrymen, he closed his brief reference to the death of Mr. Maclise with what might almost without change be at this day spoken in memory of Dickens himself;—"Incapable of a sordid or ignoble thought; gallantly sustaining the true dignity of his vocation, . . no artist, of whatsoever denomination, ever went to his rest leaving a golden memory more pure from dross, or having devoted himself to his art with a truer chivalry." For, as we look back upon the long, and, in one sense, uneventful life which came to so sudden a close last midsummer, there is nothing which strikes and touches us so much in it as this: that it was devoted almost entirely, that it was devoted exclusively and single-mindedly, to the art which ennobled it and made it great. It would be an unjust and impotent objection against this, to say, that because Dickens was from the first—or all but from the first—successful in the line of life which he had chosen, interest pointed the same way as ambition, and ambition the same way as creative impulse. Certainly, in this country of ours the rewards

are neither few nor scant which the public bestows upon literary success. And happily, in our own days, literary merit needs no other patron than the public. No great nineteenth-century poet needs to embitter his existence by "losing good days that might be better spent;" and "wasting long nights in pensive discontent; speeding to-day, to be put back to-morrow; feeding on hope, to pine with fear and sorrow." No nineteenth-century humourist needs to bully the great ones in the realm to stand in awe of him; or, while he lords it over his fellow-writers, to be, to the end of his days, the slave of the booksellers. But while literary success in our days lies in a more straightforward path for literary merit, the temptations of both have increased. Among them is the temptation which it is more difficult perhaps for an Englishman than for the citizen of most other countries to resist—to make his literary honours merely a stepping-stone to a political career and to mere social distinction. The members of more than one popular constituency, during Mr. Dickens's life, were of opinion that his laurel lacked its greenest leaf till he should consent to represent them in Parliament; and there was in certain quarters a chronic murmur, why Charles Dickens had not been made a lord, or at all events a baronet or a privy-councillor. Had Mr. Dickens regarded literature merely as a means to an end, he might probably have contrived to compass one, if not all, of these distinctions; but he regarded literature as the end of his life itself, and by what he accomplished in it he desired to be judged by his contemporaries and by posterity.

The best and most honourable tribute, therefore, that can be paid to his memory, is not, indeed, to forget the man in his works, but in his works to seek out the man. The mere outward circumstances in his life have but a passing interest. The months have flown swiftly since the day of his death; and the time has already gone by when a curiosity lingering over mere outward details was at all events excusable. Naturally enough, at the first moment, when the man himself was still fresh in our remembrance—when the sudden impression of his having been taken away in the midst of an active career was still upon us,—we thought less of his services as a whole than of the details which we could personally recall, or which others could recall for us. We remember, or forget them now, with a better sense of their proportion to that which Dickens's friends and fellow-countrymen have really lost in him.

As for the harmless gossip which attached itself to almost every picture and every piece of pottery belonging to Mr. Dickens—(down to the stuffed raven, who, as we thought, was purchased by

the most fearless of enthusiasts, but who turned out to have been secured by an enterprising photographer)—it naturally enough interested us at the moment. It has vanished from our minds as the pictures have vanished from their familiar walls at Gadshill; with it have gone the details about the amount of Mr. Dickens's personal property; about the way in which he disposed of it; the obscure insinuations as to his opinions on subjects with which the public had no concern; and one or two stray attempts to revive forgotten scandals, which may or may not have rested on misconception, but which it is certainly no man's business to make the subject of common talk.

We all live in hopes that even our own generation may see the life of Dickens really written. The public desires no vamped-up compilation, cheaply got up for a cheap market—if the book be good, it will soon become cheap; we can wait till a competent hand has addressed itself to the task. A good biography, such as Mr. John Forster, one of Dickens's most intimate friends, wrote of Oliver Goldsmith—such as the world hopes he may be induced to write of Charles Dickens himself,—will contain enough detail to leave to posterity a warm and living picture of the man; but will subordinate that detail to the great design, and not dissolve the mighty current of a great career into a numberless sea of petty facts. But while we can wait for such a biography as this, the time has, I think, come for every man who calls himself an admirer of Dickens, and who believes that his children and children's children will honour the name and love the author whom he honours and loves, to enquire into the grounds of this admiration, and of the emotion which it engenders.

It is not, of course, possible to suppose that the unparalleled popularity at present attaching to the name of Dickens will endure in the same degree and in the same extent. In the first instance, what may be termed the *accidents* of his literary effects, will lose in the eyes of posterity the attractiveness which they have possessed for his own age. The time will come when many passages in Dickens will need a commentator; and though we of the teaching class are fond of commentating authors, yet we agree with the larger half of the world in thinking those authors most enjoyable who explain themselves. I take up my edition (the last, I believe) of the book with which I verily believe most Englishmen of the present generation would not object to be sentenced to a moderate term of solitary confinement—of course, I mean the *Pickwick Papers;* and I find its author, in the preface, written many years after its composition, using these expressions:

"I have found it curious and interesting, looking over the sheets of this reprint, to mark what important social improvements have taken place about us, almost imperceptibly, since they were originally written. The licence of counsel, and the degree to which juries are ingeniously bewildered, are yet susceptible of moderation; while an improvement in the mode of conducting Parliamentary elections (and even Parliaments too, perhaps) is still within the bounds of possibility. But legal reforms have pared the claws of Messrs. Dodson and Fogg; a spirit of self-respect, mutual forbearance, education, and co-operation for such good ends, has diffused itself among their clerks; places far apart are brought together, to the present convenience and advantage of the public, and to the certain destruction, in time, of a host of petty jealousies, blindnesses, and prejudices, by which the public alone have always been the sufferers; the laws relating to imprisonment for debt are altered; and the Fleet Prison is pulled down."

"Who knows," he continues, in the same vein, "but by the time the series reaches its conclusion, it may be discovered that there are even magistrates in town and country, who should be taught to shake hands every day with Common-sense and Justice; that even Poor Laws may have mercy on the weak, the aged, and unfortunate; that schools, on the broad principles of Christianity, are the best adornment for the length and breadth of this civilised land."

And so forth, speaking of social changes which he saw in progress around him, and of which—Heaven be praised!—he lived long enough to witness at least the earnest beginning, leading, we may trust, to full accomplishment. So, again, we may look forward to a time when much of the effect of such a book as *Bleak House* will be considerably diminished by the difficulty in understanding its subject. Indeed, I recall an anecdote of the present Lord Chancellor protesting to Mr. Dickens that the court in question was in a fair way to redeem itself from the unpopularity to which he had given so trenchant an expression; and of the author of *Bleak House* receiving the intelligence with pleasure, not unmixed with a shade of incredulity. And in pointing out this probable cause of a future diminution of interest in some of Dickens's most popular works, I am not speaking unadvisedly, for I have heard men of intelligence in our own day exclaim on the impossibility of reading our great novelists of the eighteenth century, because the state of society which they describe is so difficult to understand as to make their ground almost a foreign one to readers of the present generation.

Again, we cannot believe—at least the general course of the history of literature points directly the other way—that the *form* in which Dickens, following the taste of his times perhaps even more than the bent of his own genius, cast his literary creations,

will not at some future time become more or less obsolete. Dickens's fame, of course, rests in the main upon what he did as a writer of *novels*. Now, in whatever form he might have written, the gift of his genius, his all but infinite humour, and his all but inexhaustible imagination, would have shone; but that he became a great *novelist* was due, in some measure at least, to the accident of the literary tastes of the times in which he lived and wrote. I will not, for instance, conceal my own belief, that if he had lived in another epoch, he would have been attracted even more strongly to writing plays than he was in our own days to writing novels. Before I close, I hope to say something on his dramatic powers, which both in the clear drawing of characters and in the happy invention of situations were extraordinary; and assuredly his love for the stage can have escaped no reader of his works. It was very wide and very enduring. As one who had special opportunities for understanding Dickens's tastes in this direction has pointed out to me, it included entertainers of almost every description. It was because he loved the drama so well that he had so keen an eye for the little absurdities and extravagances of its professors. Who does not remember the immortal Mr. Vincent Crummles, of the Theatre Royal, Portsmouth, the proprietor of the pony with the theatrical education, and of the vehicle of unknown design, in which the manager himself was wont to occupy the front seat, while

"The Master Crummleses and Smike were packed together behind, in company with a wicker basket, defended from wet by a stout oilskin, in which were the hand-swords, pistols, pig-tails, nautical costumes, and other professional necessaries of the aforesaid gentlemen?"

And Mrs. Crummles, who in private life "wore her hair (of which she had a great quantity) braided in a large festoon over each temple;" and Miss Ninetta Crummles, the infant phenomenon, who first appeared before Nicholas Nickleby—

"in a dirty white frock with tucks up to the knees, short trousers, sandaled shoes, white spencer, pink gauze bonnet, green veil, and curl-papers; who turned a pirouette, cut twice in the air, turned another pirouette, then, looking off at the opposite wing, shrieked, bounded forwards to within six inches of the footlights, and fell into a beautiful attitude of terror, as a shabby gentleman in an old pair of buff slippers came in at one powerful slide, and, chattering his teeth, fiercely brandished a walking stick. 'They are going through the Indian Savage and the Maiden,' said Mrs. Crummles."

Of this good-natured fondness for everything connected with the stage, there are many traces in Dickens's works to the last, from the memoirs of the excellent clown, "Joe" Grimaldi, which he took the trouble to edit and make readable, down to the charming occasional papers of his later years, where the description of "Two Views of a Cheap Theatre" is admirably true to nature—or shall I say art?—where the "Christmas Tree Theatricals" form one of the pleasantest accompaniments of the "Christmas Tree;" where, even in the quiet town of Dullborough, the Uncommercial Traveller turns his steps to the theatre, "in which sanctuary he had in his youth come to the knowledge of many wondrous secrets of nature;" and even at the seaside at Pavilionstone there is time to remember the efforts of "poor theatrical managers." Mr. Dickens, as is universally known, was himself a most admirable actor; his performances in private theatricals live in the memory of many, as marvellous for their vigour and vivacity; and we who have seen him only before his reading-desk recall some of his sudden assumptions of character—such as that of the Jew Fagin or old Justice Stareleigh, with a distinctness of impression left upon us by few impersonations on the actual stage. I am not aware whether Mr. Dickens's impersonation was intended as a portrait; it is well known that the character was not without a malicious design of the kind. The original of Mr. Justice Stareleigh seems to have been a model of intelligent obtuseness. Perhaps you have heard of a story illustrating this. He was passing the statue of Canning, then newly erected, opposite the Houses of Parliament, in all the freshness of the verdant hue usually observable in fresh compositions of bronze. "I should think," said the judge, referring to the colossal size of the statue, "that Mr. Canning was not so large as that in life." "No, *nor as green*, was the reply." This strong personal taste would have combined with Mr. Dickens's gifts of genius in a dramatic direction to render him more effective as a playwright than any our later literature has known. As it was, he never wrote anything dramatic except, quite in his early days, a pretty little opera; the taste of the times led him irresistibly to the *novel*.

But is it certain that this taste will continue? Is it certain that the novel, like other forms of literature, will not in time give way to another? There is nothing to exempt it from the fate of all other literary forms; nothing to ensure it an everlasting endurance. I do not mean that in our own time we need look forward to a failure in the supply which at the present day seems endless; or to the demand which seems fully commensurate to it. But it is

probable that the time will come when this particular form of literature will fail to exercise an exceptional attraction; and when that time comes, the great writers who, like Dickens, have adopted it will suffer with the small, for whom neglect is in any case inevitable.

Lastly (if I am not delaying you too long on the threshold), as the years go on, as the true fame of the great men of our own age mellows in their progress, much will be lost of the kind of popularity which they could only possess for the generation to which they belonged. It is with the favourites of an age as with the familiar associates of an individual life. When we recall to our minds those whom we knew well and love dearly, what is it that we affectionately remember and that it gives us constant pleasure to dwell upon? Certainly not always only the merits for which we esteemed and the virtues for which we honoured them. Their little foibles, their tricks and oddities, their familiar extravagances which usage endeared to us, are present to us as so many sunny memories; we cannot think of them without their weaknesses, and their very failings as part of them are endeared to us. But coming generations, our sons and their sons after them, will only esteem the men and women of the past for what they were worth; they have scant piety for those accidents which to us are hardly distinguishable from essentials. And so with a great writer whom his own age has grown to love. Mr. Dickens as an author had, especially in his later works, acquired a manner so distinctly his own, that it frequently fell into what is called *mannerism;* but to his public his faults were often inseparable from his merits; and when our critical consciences told us that he was astray in one of his favourite directions, the severest censure we had for him was that he was growing "more like himself" than ever. But future generations will judge from a different point of view. They will, and they ought, to scan more closely the merits and the demerits of the great writer's manner; and they will be less willing to tolerate what they consider bad for the sake of what they acknowledge as good. And they will also note, more keenly than ourselves, how it was precisely the mannerism of Dickens—*i.e.*, his exaggeration of his peculiarities—which his followers were able to imitate, and by imitating which they flooded our literature with a mass of writing which *we* enjoyed, more or less, because it was so like Dickens, but for which *they* will have no similar liking. Sydney Smith says somewhere, that he would undertake to teach anybody *wit*—*i.e.*, the kind of wit which can be learned—in a course of six lessons; and some of the imitators of Mr.

Dickens seem to have come by his manner without very much more trouble. But future generations will reject the mannerism in the imitations, and they will not approve it in the great writer himself.

If then, this be the case, if there is much in the *subject*, in the *form*, in the *manner* of Mr. Dickens's works, which, so far from giving vitality to them, will injuriously affect their fame and popularity, and make them less enjoyable to our successors than they are to ourselves, then surely every lover of Dickens, everyone who believes that his name and his works will endure in our literature, may ask himself the question—What are the *essential elements* of his literary genius? What is that which ensures, as we believe, a life to his works which will exist with the language itself; what is that which is not merely accidental in the popularity which he enjoys now, and on which his fame will rest in ages to come?

May I, without immodesty, attempt in part at least, to answer these questions? For my wish is to give reasons for the conviction which I believe we all share, that the name of Charles Dickens is not a mere waif upon the tossing current of time, but an inheritance which, without shame for having gloried in it ourselves, we may confidently hand down to the generations which shall succeed us.

In Shakspere's tragedy of *Hamlet* there is a very wise critic—wise enough in his own estimation to be able to overlook the circumstance that he is a fool in the opinion of everyone else—by name Polonius, who is all for nice distinctions, and who takes occasion to remind us that the drama is divided into "tragedy, comedy, history, pastoral—pastorical-comical, historical-pastoral, tragical-historical, tragical-comical-historical-pastoral, scene undividable or poem unlimited." You would probably think me what Hamlet thought Polonius, if I were to enter into a similar attempt to show what are the several kinds or classes of novels. But I may say this, that the distinction between novels of *character*, novels of *incident*, and novels of *manner*, has in it nothing either unintelligible or far-fetched. Is it not easy, or, indeed, possible, to place every novel absolutely under one or the other of these heads; but it is certain that nearly every novel is in the main of one of these three kinds. In other words, a novel may claim our attention chiefly on account of its story, on account of the skill with which that story is constructed, and of the powerful way in which the events of which it tells are brought forward and put together. That is the novel of *incident*—the novel which engages our interest on account of its plot. It is a kind which has never lost its popularity, from the days of *Robinson Crusoe* down to the days of *The Woman in White;*

for I suppose I may count among my hearers some who have, like myself, had their souls harrowed, and their night's rest disturbed by that awesome tale. Again, a novel may interest us chiefly on account of its *descriptive power*, by reason of the faithful accuracy with which it pourtrays the life and ways of men either of our own day or of any period of the past, either of our own country or of some foreign land. That is the novel of *manners*—the novel in which our English writers of the last century have excelled, perhaps, all other schools; and of which Smollett, who so faithfully describes the manners of people who, in one sense certainly, had no manners at all, is perhaps the foremost representative. Lastly, there is the novel which chiefly directs itself to trace the differences, to delineate the growth, and to illustrate the passions and humours of particular types of men and women. That is the novel of *character*, which some think the highest kind of all—of which our literature boasts many masters, and our own age not a few worthy to rank high in our literature. Now it is very rare to find a novel which is *exclusively* of one or the other of these classes, and a novelist who has not attempted to shine in them all, but there are not many novels which are successful in the attempt, and there are, as I have already said, very few novelists indeed who have been masters of all three.

The great writer of whom we are speaking, was not equally gifted by nature in every one of these directions. The novel of *incident* requires what rarely comes by nature, great artistic skill of a peculiar kind; experience teaches much, but cannot wholly supply, the defects of nature. Mr. Dickens knew that he was comparatively weak in this direction; and he accordingly here applied himself with the most visible effort to learn by experience and by example; but effort, when it is perceived, diminishes the effect, and, to some extent, spoils the enjoyment of any work of art or literature.

Let us dwell for a moment on this point. It is not quite fair to judge a writer by his earliest writings, even if they be the most popular of any which he has produced. Thus a serious injustice is often—involuntarily, no doubt—done to the *artistic* merits of Mr. Dickens by taking the immortal *Pickwick Papers* as the text-book for judging of his writings as a whole. In some ways he never surpassed this early effort; but, from the point of view under which we are at present considering it, it was crude and imperfect; and could not, indeed, in the nature of the case, be otherwise. For the *Pickwick Papers* as is well known, were not at first intended to be a novel at all; but grew out of a series

of sketches originally intended to accompany a series of comic prints illustrating the adventures of Cockney sportsmen. When a plot has no beginning it cannot have a middle, and it only has an end because every book has a last page, just as even the worst tragedy has a last scene, in which, as a matter of course, all the bad characters are killed off, and all the good married off. For the same reason, when an author starts without any clear idea of a character, he cannot carry that character out consistently through his story; accordingly, our friend Mr. Pickwick, in the earlier part of the book, is a ridiculous old donkey, and in the later part a benevolent old gentleman, frequently as shrewd as he is benevolent. Sam Weller, on the other hand, comes on the stage comparatively late; he is the author's own creation, and he is perfect from first to last—from his first appearance in the inn-yard, intent upon the illustration of eleven pair of boots—

> "Eleven pair o' boots, and one shoe as b'longs to Number Six, with the wooden leg. The eleven boots is to be called at half-past eight, and the shoe at nine. Who's Number Twenty-two, that's to put all the others out? No, no! Reg'lar rotation, as Jack Ketch said when he tied the men up: sorry to keep you a-waitin', sir; but I'll attend to you directly."—

Through his relations as an ardent lover to Mary, a fatherly son to old Mr. Weller, an unwilling step-son to the "widder," a deadly foe to the Shepherd, and a servant and protector to Mr. Pickwick, down to his final confession of faith:

> "If you vant a more polished sort of feller, vell and good—have him; but vages or no vages, notice or no notice, board or no board, lodgin' or no lodgin', Sam Veller, as you took from the old inn in the Borough, sticks by you, come what come may; and let ev'rythin' and ev'rybody do their wery fiercest, nothing shall ever perwent it."

But in general, as a novel of character, and still more so as a novel of incident, the *Pickwick Papers* will not stand any severe test; and the nature of their origin forbids our applying it to them.

No sooner, however, had Mr. Dickens undertaken the composition of a regular work, conceived from the first and constructed as an organic whole, than he began to display an unmistakable anxiety, which seems not to have abandoned him to the last, adequately to perform that part of the novelist's task, which lies not only in the invention, but also in the judicious and artistic arrangement of incidents. Compared with his other powers, his power of *construction*, however, remained his weak point to the last, though he endeavoured to make good a natural defect by unabated and unwearying labour. As a constructor of plots, he grew more

elaborate and artificial as he went on, but not, I think, more effective and artistic. *Oliver Twist*, the first of his novels, is simply and powerfully put together; in *Nicholas Nickleby*, the interest in the story is already fainter; in the *Old Curiosity Shop* the original thread is flung aside altogether, and the story itself totters to its end almost as feebly as the old man whom Little Nell led through the country lanes. *Martin Chuzzlewit* is quite improbable; and the visit to America, an inimitable episode in itself, is simply foisted into the general action; *David Copperfield*, poor boy, gets into his troubles for no particular reason, and gets out of them as easily as he gets into them. In his later works, Mr Dickens, perhaps under the influence of Mr. Wilkie Collins's example, attempted plots of extreme intricacy. Indeed, he seems almost to hint as much in the preface to his *Tale of Two Cities*, of which he informs us he first conceived the main idea when he was acting with his friends and children in Mr. Wilkie Collins's drama of the *Frozen Deep;* yet the tale itself is one of the very few of Mr. Dickens's works which require an effort in the perusal. The master of humour and pathos, the magician whose potent wand, if ever so gently moved, exercises effects which no one is able to resist, seems to be toiling in the mechanician's workshop, and yet never attains to a success beyond that of a more or less promising apprentice. To take only his last two works, is there any man not blessed with the experience of a detective policeman, who could furnish an intelligible account of the plot of *Our Mutual Friend.* And if he is at times obscure when in the end he of course means to be clear, he is elsewhere transparent where he intends to be secret. Have you read the *Mystery of Edwin Drood*, which, alas! its author was not himself to unravel. We have lost much by its sudden interruption; but not the key to the mystery. I certainly do not flatter myself with being more than ordinarily acute in penetrating such problems; but after reading the very first number of that work I told a lady who was beginning it that it would be no mystery to her, and she found it out at once.

If Dickens was never destined to attain to high distinction as a constructor of plots, the wonderful fertility of his imagination, and the marvellous dramatic sense which he in so many ways displayed, could hardly fail to make him eminent as an inventor of *situations.* I need hardly point out the distinction; it is in a word, the distinction between the devising of effective scenes, and the combining of effective scenes into a harmonious whole. Nor need I from the wealth of instances which at once crowd into the memory,

select more than one or two instances in illustration. Do you remember, in that beautiful work *David Copperfield*, the novel of Charles Dickens's own heart, which it is not wonderful that many should have thought a reflection of much in his personal experience, the shipwreck on the Yarmouth Sands:

"The wreck, even to my unpractised eye, was breaking up. I saw that she was parting in the middle, and that the life of the solitary man upon the mast hung by a thread. Still he clung to it. He had a singular red cap on, not like a sailor's cap, but of a finer colour; and as the few yielding planks between him and destruction rolled and bulged, and his anticipative death-knell rung, he was seen by all of us to wave it. I saw him do it now, and thought I was going distracted, when his action brought an old remembrance to my mind of a once dear friend.

"Ham watched the sea, standing alone, with the silence of suspended breath behind him, and the storm before, until there was a great retiring wave, when, with a backward glance at those who held the rope which was made fast round his body, he dashed in after it, and in a moment was buffeting with the water—rising with the hills, falling with the valleys, lost beneath the foam, then drawn again to land. They hauled in hastily.

"He was hurt. I saw blood on his face, from where I stood, but he took no thought of that. He seemed hurriedly to give them some directions for leaving him more free—or so I judged from the motion of his arm—and was gone as before.

"And now he made for the wreck, rising with the hills, falling with the valleys, lost beneath the rugged foam, borne in towards the shore, borne on towards the ship, striving hard and valiantly. The distance was nothing, but the power of the sea and wind made the strife deadly. At length he neared the wreck. He was so near that with one more of his vigorous strokes he would be clinging to it, when a high, green, vast hill-side of water, moving on shoreward from beyond the ship, he seemed to leap up into it with a mighty bound, and the ship was gone!

"Some eddying fragments I saw in the sea, as if a mere cask had been broken, in running to the spot where they were hauling in. Consternation was in every face. They drew him to my very feet—insensible—dead. He was carried to the nearest house, and no one preventing me now, I remained near him, busy, while every means of restoration were tried; but he had been beaten to death by the great wave, and his generous heart was stilled for ever.

"As I sat beside the bed, when hope was abandoned, and all was done, a fisherman, who had known me when Emily and I were children, and ever since, whispered my name at the door.

"'Sir,' said he, with tears starting to his weather-beaten face, which with his trembling lips were ashy pale, 'will you come over yonder?'

"The old remembrance that had been recalled to me was in his look. I asked him, terror-stricken, leaning on the arm he held out to support me:—

"'Has a body come ashore?'
"He said, 'Yes.'
"'Do I know it?' I asked then.
"He answered nothing.
"But he led me to the shore, and on that part of it where she and I had looked for shells, two children—on that part of it where some lighter fragments of the old boat, blown down last night, had been scattered by the wind—among the ruins of the home he had wronged—I saw him lying with his head upon his arm, as I had often seen him lie at school."

And do you recall a scene of a most opposite description—steeped in holy calm instead of the strife of the elements; this, too, a death-bed scene, but in place of the waves of the furious ocean, the tranquillity of an ancient village:—

"Waving them off with his hand, and calling softly to her as he went, he stole into the room. They who were left behind drew close together, and after a few whispered words—not unbroken by emotion, or easily uttered—followed him. They moved so gently that their footsteps made no noise; but there were sobs from among the group, and sounds of grief and mourning.

"For she was dead. There, upon her little bed, she lay at rest. The solemn stillness was no marvel now.

"She was dead. No sleep so beautiful and calm, so free from trace of pain, so fair to look upon. She seemed a creature fresh from the hand of God, and waiting for the breath of life; not one who had lived and suffered death.

"Her couch was dressed with here and there some winter berries and green leaves, gathered in a spot she had been used to favour. 'When I die, put near me something that has loved the light, and had the sky above it always.' Those were her words.

"She was dead. Dear, gentle, patient, noble Nell was dead. Her little bird—a poor, slight thing, the pressure of a finger would have crushed—was stirring nimbly in its cage; and the strong heart of its child-mistress was mute and motionless for ever.

"Where were the traces of her early cares, her sufferings and fatigues? All gone. Sorrow was dead indeed in her, but peace and perfect happiness were born; imaged in her tranquil beauty and profound repose.

"And still her former self lay there, unaltered in this change. Yes. The old fireside had smiled upon that same sweet face; it had passed, like a dream, through haunts of misery and care; at the door of the poor schoolmaster on the summer evening, before the furnace fire upon the cold wet night, at the still bed-side of the dying boy, there had been the same mild lovely look. So shall we know the angels in their majesty after death.

"The old man held one languid arm in his, and had the small hand tight folded to his breast, for warmth. It was the hand she had stretched out to him with her last smile—the hand that had led him on, through all their wanderings. Ever and anon he pressed it to his lips; then

hugged it to his breast again, murmuring that it was warmer now; and, as he said it, he looked, in agony, to those who stood around, as if imploring them to help her.

"She was dead, and past all help, or need of it. The ancient rooms she had seemed to fill with life, even while her own was waning fast—the garden she had tended—the eyes she had gladdened—the noiseless haunts of many a thoughtful hour—the paths she had trodden as it were but yesterday—could know her never more.

"'It is not,' said the schoolmaster, as he bent down to kiss her on the cheek, and gave his tears free vent, 'it is not on earth that Heaven's justice ends. Think what earth is, compared with the world to which her young spirit has winged its early flight; and say, if one deliberate wish expressed in solemn terms above this bed could call her back to life, which of us would utter it!'"

These scenes, and many others as perfect in other ways, both in effect and in conception, occur in novels which, in construction, leave much to be desired; a proof of a fact on which you will, I am sure, not desire me to dwell any longer; that of two kindred merits Dickens possessed one in an extraordinary, the other only in a comparatively inferior degree.

We pass to another, perhaps the most important aspect of his literary workmanship. As a novelist of *character*, Dickens works, as all but the very greatest of human writers work, within a limited range, but within this range he excels. Indeed, I do not know why I should make any exception whatsover; for even in the case of Shakspere himself there are limits to that sympathy which is the parent of humour, which again is the creator of characters. For humour has been well defined as the power of understanding, and appreciating the tastes, the prejudices, the likes and dislikes, in a word the *humours* of others; the power to understand and reproduce "those various inclinations which nature gives to ages, sexes, nations," and to cast over them that veil of sympathy which shows us the likeness of men in their unlikeness; so that, while, to quote the same poet—

"Whate'er custom has impos'd on men,
Or ill got habit which deforms them so,
That scarce a brother or his brother know,
Is represented"—

men learn beneath the diversity of mankind to read the lesson of its brotherhood. But none of us, even those gifted with the most marvellous insight into character, can understand every man in his humour; and if Dickens therefore moves within a restricted range, it is only because genius itself is not, which only impotent flattery proclaims it to be, omniscient.

In his works we therefore find an extraordinary, but not an absolutely exhaustive, variety of character-studies. I wish to speak rather of what we find, than of what we do not find there; and I will not therefore dwell on the absence of certain types which it is strange to find all but unrepresented in the works of the most popular of modern English writers. A simple reference will suffice to the fact, that he never gives us the character which to the minds of most modern Englishmen is the most acceptable type of human worth—the man of public spirit; that he never draws the positive to the negative which he so constantly satirises, the Bounderbies who burlesque civic virtue and the people "with a small p," who in the Circumlocution Office, and elsewhere, condescend to misgovern us. Again, it is remarkable that he who beyond all question was conscious of the infinite value of a single-minded devotion to the claims of art, who was ready to recognise its elevating influence in others, and to sacrifice to it all secondary views in his own career, should never have essayed the portrait of an artist devoted to art for its own sake alone.

The reason of this seems to be, that Mr. Dickens's artistic sympathy was limited to other types of virtue—types which I may possibly allow myself to call those of the private or domestic kind. His sympathy with the affections of the hearth and the home knows no bounds, and it is within this sphere that I confess I know of no other writer—in poetry or prose, amongst ourselves or other nations—to compare to him. Where shall I begin and where end in speaking of this side of his genius? Who ever understood children better than he? Other writers have wondered at them; he understands them,—the romance of their fun, the fun of their romance, the nonsense in their ideas, and the ideas in their nonsense. It was only the other day that I heard him read, in the Free Trade Hall, a portion of one of his best Christmas serials—*Boots at the Holly Tree Inn*—it is called—a story of baby love which would have drawn smiles and tears from Mr. Gradgrind, and which, as I am here to testify, was recognised on the spot as absolutely true to nature by a mother in the gallery, whose sympathy I thought at the time would be too much for Mr. Dickens himself. Who could picture better than he that curious animal, the British boy? Why, he understood him in every phase and under every aspect of his existence, whether he was the pupil of Dr. Blimber's classical academy or of Mr. Fagin's establishment of technical education. Who, again, fathomed more profoundly that sea whose dimples so often deceive us as to its depth, the mind of a young girl? Again and again he has drawn

that character in various types, inspiring in turns compassion, love, reverence—from poor little Dora, who could not keep her Davy's house in order, but who could hold his pens for him when her clever boy was writing his clever books, to Agnes in the same story, the guardian angel of his better self; and, again, in the same story, little Emily, so sweet and so fragile; and he has repeated it with never-ending freshness and truth, down to his very last unfinished tale, where Rosebud, who would not kiss Eddy because her lips were sticky, was to be the heroine of a tale of womans' faithfulness to the end.

But society, we know, is not made up of boys and girls; and in Mr. Dickens's characters of men and women we must seek for his most sustained efforts. Here again he moves within certain bounds. The effects of passion upon character he has very generally preferred to depict on the background of domestic life. The types which he chiefly delights in reproducing are accordingly those with which most of us have opportunities enough of comparing ourselves and our neighbours—our neighbours in particular, as the late Mr. Thackeray would have observed. Avarice and prodigality, pride and humility, utter hypocrisy and a gushing openness to the influence of the moment, philanthropy and misanthropy equally unbounded in degree. Jonas Chuzzlewit and Richard Carstone, Mr. Dombey and Tom Pinch, Pecksniff and Micawber, the Brothers Cheeryble and Quilp, are only among the illustrations which start most readily to every mind, but each of which might be multiplied, in many cases multiplied almost a hundred fold, from the works of the same author. Now, if we consider these types, we shall, I think, find the reason of Mr. Dickens's predilection for the representation of them. They are the favourite growths of our own age and our own country. England is a wealthy land, and as one in which there are great extremes of wealth and poverty, is prolific both of misers and spendthrifts, for there is so much money to get, and there are so many ways of spending it, that the temptation to the developement of either kind of character is peculiarly strong among us. As an old, as well as a rich country, England is specially favourable to the growth of pride of all kinds; and the humility which has its root in the conviction that a man's duty lies in the station of life to which Providence has called him, is in itself, in part, at least due to the fixed order of classes which has taken root among us. As a professedly, and in some of its classes, traditionally religious community, setting a high value upon the maintenance of forms which are accounted among the best safeguards of the

meaning which underlies them, we are frequently exposed on the one hand to see the forms assumed without the contents, and on the other peculiarly sensitive to that recklessness of all restraint which, in certain kinds of mind, is the natural reaction against any vigorous outward code of law. And, as in active exertion at least we are the most philanthropic of nations, so we have always numbered among us an excessive proportion of eccentrics tending towards the other extreme; universal benevolence jostling as it were in the streets with sullen spleen. If this be so, it will not be difficult to discern why Dickens should not only perpetually dwell upon these types, but should generally present them in a form highly coloured and intensely marked. Let me take only a single example. *Hypocrisy* is a vice so in vogue among us, it is so inevitable a product of the greatest movement that ever pervaded our people—the Puritan movement—that English literature teems with representations of it from the days of Queen Elizabeth downwards; from the days of Ben Jonson's Volpone and Sheridan's Joseph Surface to those of Mr. Chadband, whose unctuous countenance appeared to shine with the light of Terewth, but was in reality only greasy from the continuous consumption of muffins, and the 'umblest of the 'umble, Uriah Heep. Dickens alone has furnished a whole gallery of English hypocrites; and in no class of characters has he been at once more faithful to nature, and more careful of avoiding offence to the true while gibbetting the false. The masterpiece among them all is Mr. Pecksniff, all virtue and shirt-collar, that "most exemplary man, fuller of virtuous precept than a copy-book," whom his enemies likened "to a direction-post, which is always telling the way to a place, and never goes there." What is so perfect about Mr. Pecksniff is his consistency: this is the mark of the consummate hypocrite, who beginning by deceiving others with a purpose, ends by keeping up the practice within his four walls, before his own children, and almost to himself, till his hypocrisy becomes part of his being. Such an one was Mr. Pecksniff, architect and surveyor, "of whose architectural doings nothing was clearly known, except that he had never designed or built anything; but it was generally understood that his knowledge of the science was almost awful in its profundity;" but who might certainly be said to be "a land surveyor on a large scale, as an extensive prospect lay stretched out before the windows of his house." Mr. Pecksniff was so successful because neither out in the wicked world, nor at home with his daughters, Cherry and Merry, as they were fondly called for Charity and Mercy, was he ever forgetful of his cue; nothing,

from a piece of cold-blooded villany to a bowl of hot punch, could take the hypocrisy out of him; when he turned his most faithful friend and servant out of his house, he waved his hands in an attitude of blessing on the doorstep, and when he was so drunk that his friends who had put him to bed could not keep him there, he fluttered on the landing, calling upon those below: "My friends! let us improve our minds by mental enquiry and discussion. Let us be moral. Let us contemplate existence."

There was admirable artistic taste, as well as moral truth, in the way in which Mr. Dickens contrasted the hateful vice of hypocrisy with the virtue which he most excelled in describing—that of simplicity, own sister to truthfulness, honesty, and neighbourly goodwill. Mr. Dickens was never happier than when dwelling upon such characters as Tom Pinch, or Trotty Veck, or Martha Peggotty; here pathos and humour, which are, I think, but different forms of the same thing, were indissolubly blended. And he never erred by treating his characters in that patronising way which other humourists have adopted: he never condescended to them, never exhibited them to his readers with a benevolent smile of patronage. Still less, I may take this opportunity of adding, was he likely to fall into that absurd fashion which is observable in some popular novelists of the present day, who stand, or pretend to stand, outside their own creations, who apostrophise their characters with a "Villain, why didst thou mar the peace of that innocent family," or "Scoundrel, why didst thou bring thy father's grey hairs with sorrow to the grave"—to which the villain or scoundrel in question, had they the opportunity of a reply, might fairly make answer: "Then, why did you make me do it?" No, Dickens lives *with* and *in* his characters; he neither plays with them, nor with the effect which they produce.

But I fear I must dwell no longer on this, the most remarkable aspect of our great humourist's genius, otherwise I should have liked to say something about the utterly odd and eccentric characters which he of late in particular loved to introduce into his works. With all the humour which they display—I am thinking of such characters as Mr. Quilp, the diabolic dwarf, and Miss Mowcher, the benevolent pygmy, and a hundred more—with all their fidelity to nature in her grotesque vagaries (for I believe they are the ablest *copies* of all), they are studies of individuals only, not of whole classes of men and women, and therefore less interesting to us. I should have liked, too, to have dwelt on Dickens's pictures of the human mind in its decay, and to have contrasted them with the more terrible but hardly more true

characters of mad folk drawn by Shakspere himself. But I must pass on, for I have yet a few words to say on the third and last head of my general subject.

As a novelist of *manners* Dickens is, in his own sphere, without an equal. In this direction he had his earliest successes; and in this direction his hand never lost its cunning. Even before *Pickwick* was written, the *Sketches by Boz*, had shown that the life of our middle and lower classes, and more especially the middle and lower classes of that great city where it displays itself in the most multitudinous variety, of London, was the chosen sphere for his inimitably faithful observation and inimitably faithful reproduction. In *Pickwick* he never left this ground; in *Oliver Twist* he explored some of its darkest passages, and was able to represent them at once with truth and with good taste. In *Nicholas Nickleby* he for the first time ventured upon sketching the manners and customs of what were intended not of course as types of the aristocracy, but *in manners and customs* were supposed to be faithful portraitures. This attempt he afterwards repeated in *Dombey and Son*, in *Bleak House*, in *Our Mutual Friend*, and elsewhere; but he never succeeded in producing anything but caricatures. Why this should have been so, I will not pretend to determine; that it was so, is my deliberate opinion. Even in the *Mystery of Edwin Drood* he seems, accidentally no doubt, to enter into competition with a very popular novelist of the present day, Mr. Anthony Trollope, as a describer of clerical life. I don't pretend to know in what way Deans and Canons talk when they are at home; but I will venture to say they don't talk in the way Mr. Dickens seems to suppose. The truth is that there were limits which Dickens could not pass with safety: there is nothing to be said on the subject except that those limits in his case included a variety which is in one sense infinite. To a wonderful natural power, he added the most constant habits of observation. It is known that he spent a certain time of every day in walks, whether in the country or in London. Thus he came to know not only the streets and the highroads, but their denizens and their wanderers, as it were by heart. And I have heard that when he undertook to describe any class of manners peculiar and out of the way, be never failed to devote a special study to it. In his stirring tale of *Hard Times*, the terrible earnestness of the narrative is relieved by the oddities of Mr. Sleary, the proprietor of a circus, and of his colleagues. It is said that the wonderful naturalness of these details was the result of a repeated actual study of the manners and costumes not only in the ring, but outside

it, of that peculiar profession. In his last story, the *Mystery of Edwin Drood*, he describes with terrible accuracy, the force of which is in no small measure due to its completeness, the habits of the opium smokers in the slums of Rotherhithe. It is said here, too, the habit of personal observation had gained him a knowledge of a population whose very existence was unknown to most of his fellow countrymen. But passing to more familiar scenes, what can equal his descriptive power with regard to a wide variety of classes of men and their surroundings. If there be among my hearers any who are unacquainted with the delightful papers of the *Uncommercial Traveller* let them turn to them as a proof how Dickens had studied, and how well he knew the England, merry and not merry, of our own day. To him the tramp, whom we pass without notice in the street, was a living reality; he could classify him with as much accuracy as the army list classifies a soldier of a particular branch of the service; and in the hostelry where he paused for refreshment, the landlady and the waiter were unconsciously standing for their photographs.

This power of observation and description extended from human life to the brute creaton, and again to inanimate objects of every kind and description. An American friend of his has published a letter in which describing his return home to England in 1868, he thus describes his reception—by his dogs:

"As you ask me about the dogs, I will begin with them. The two Newfoundland dogs coming to meet me, with the usual carriage and the usual driver, and beholding me coming in my usual dress out of the usual door, it struck me that their recollection of my having been absent for any unusual time was at once cancelled. They behaved (they are both young dogs) exactly in their usual manner; running behind the basket phæton as we trotted along, and lifting their heads to have their ears pulled—a special attention which they receive from no one else. But when I drove into the stable-yard, Linda (the St. Bernard) was greatly excited, weeping profusely, and throwing herself on her back that she might caress my foot with her great fore-paw. M's. little dog too, Mrs. Bouncer, barked in the greatest agitation, on being called down and asked 'who is this?' tearing round and round me like the dog in the Faust outlines."

And as with men and animals, so with inanimate nature and scenery, his power of observation was keenest at home. I do not know whether there is any Londoner among my hearers; if there be he will agree with me that the Thames is for ever associated in the mind of a reader of Dickens with his pictures of it from Chelsea to Sheerness. I shall never forget how that river has on many occasions recalled passages from his works to my mind;

above all, how one morning, at break of dawn, finding myself by accident in an out-of-the-way corner among the wharves by the river side, and wondering what gave so familiar an aspect to the strange surroundings, I remembered I had seen the odd picture before in Dickens. His sketches of foreign lands—both of men and scenes—are far inferior, though I am aware of exceptions; and for no other reason than this, that Dickens's descriptive power was the fruit of his humour, and that his humour sprang, as all humour springs, from sympathy.

But it is time for me to draw to a conclusion. I have left much unsaid that I would have added, could I have ventured to trespass further on your patience; but I must say one thing more before I close. I have not thought it necessary to vindicate before you the right of the novel to be considered a form of literature equal, in the hands of a master, to any other. What seems more to the purpose is to ask the question, to what has Dickens owed the mastery which he obtained over it? He owed it in no small degree to the patient and indefatigable study which he devoted to his art—to its materials as well as to its conditions. Of his studies of life I have already spoken. There never was a writer less ostentatious of his reading; but I can see in his works many traces of the fact that he read much, and chiefly good books; and we have it on undoubted testimony that in writing he worked conscientiously and hard. He owed it to the style which he perfected—I say perfected, for if in his later works he was sometimes artificial in manner, in his earliest he was comparatively rough. But primarily, and above all, he owed it to that gift of genius which no toil can secure, though neglect may fritter it away, or abuse pervert. For Dickens possessed an imagination unsurpassed, not only in vividness, but in swiftness. I have intentionally avoided all needless comparisons of his works with those of other writers of his time, some of whom have gone before him to their rest, while others survive to gladden the dulness and relieve the monotony of our daily life. But in the power of his imagination—of this I am convinced—he surpassed them, one and all. That imagination could call up at will those associations which, could we but summon them in their full number, would bind together the human family, and make that expression no longer a name, but a living reality. The oldest man has in his heart a corner where he is still a child; the youngest child has in his soul intimations of the impulses which, were he a man, would produce some of those actions which make up the history of human life. The veriest dullard, even he whose reason totters on the verge of imbecility, or lies encrusted in the slime of ignorance, at times

catches a glimpse of the better existence in advance of him; and the man and woman whom we in our weak despair call lost, at times look back to the purer and brighter moments they have left behind them. Such associations as these sympathy alone can warm into life, and imagination alone can at times discern. The great humourist reveals them to everyone of us; and his genius is indeed an inspiration from no human source, in that it enables him to render this service to the brotherhood of mankind

But more than this. So marvellously has this earth become—what assuredly Providence destined it to become—the inheritance of mankind, that there is not a thing upon it, animate or inanimate, with which, or with the likeness of which, man's mind has not come into contact; least of all an object which the hands of men have pruned or changed in substance or in aspect; with which human feelings, human aspirations, human thoughts, have not acquired an endless variety of single or subtle associations. The houses in the streets, the church tower in the distance, the bells in the church tower, the chimes of those bells at morning and at evening, the room at home, the board spread for the meal, the kettle singing and the cricket chirping on the hearth, the sun shining, the wind blowing, the waggons rumbling, the trains shrieking outside, all the sights and all the voices of the day and of the night,—they are to none of us sights and noises wholly without meanings, without memories, without associations. These associations also, which we imperfectly divine or carelessly pass by, the imagination of genius distinctly reveals to us, and powerfully impresses upon us. Where they appeal directly to the emotions of the heart, it is the power of *pathos* which has awakened them; and where the suddenness, the unexpectedness, the apparent oddity of the one by the side of the other, strike the mind with irresistible force, it is the equally divine gift of *humour* which has touched the spring of laughter by the side of the spring of tears.

This is the power wielded by an imagination like that of the great genius of whom we have spoken to-night. Do we then owe him nothing beyond many pleasant hours which have refreshed us after our day's toil, and the memory of those hours which makes us long to return to the spell of the kindly enchanter? We owe him much more than this; for he who has made human nature and its surroundings speak to us, and claim our sympathy for that to which we should have otherwise remained half deaf and half blind, has multiplied the richness of our existence, and has enabled us to hear with his ears and see with his eyes what our own were too dull to hear and to see

Modestly, as becomes a man speaking of the labour of his life, Charles Dickens once summed up the spirit of his endeavours in these words: "I felt an earnest and humble desire, and shall do till I die, to increase the stock of harmless cheerfulness. I felt that the world was not utterly to be despised; that it was worthy of living in for years." Yes, this is the task which he set himself, and the task which, by God's blessing, it was given to him to perform. I have no right to judge of the moral purpose which underlay his efforts; but I and you, and every reader of Dickens, is justified in estimating the effects of what he has actually done. Genius can accomplish many things: it can inspire to great deeds, it can fire the soul of a nation, it can wing the ambition of the young, it can transform hope into resolve, it can brighten despondency and gild even decay. The genius of Dickens was not incapable of some of these tasks, nor inactive in some of these directions. But its own bent was to a different end: that of making men feel their brotherhood, and recognise in human life those elements which among a thousand diversities of character and manners, are common to us all. This is why he deserved well of his country and of his kind. And thus we bid farewell to the memory which we have dwelt upon to-night; but a farewell which is to be followed, I trust, by many meetings with him, on the part of all of us, in those creations which he has left behind him. Will you allow me to end with words which are none the less valuable to me because they were spoken by a dear friend who was, as a boy, familiar with Charles Dickens himself, and which are none the less appropriate because they were originally spoken in a sacred place:

"It has been the common remark during the past week [the week following upon Dickens's death], that the loss of this writer has affected society in a way quite peculiar, that everyone who knew his works—and who does not—has felt a shock of pain, as if a personal tie between himself and a near and dear friend had been suddenly snapped. And the fact is strange and full of instruction. The hundred distinct characters which his imagination created, and which are as real to us as if they walked in flesh and blood, remain. They have not died with him. We do not mourn for *them*. He made us laugh and weep when he willed; but that power has been wielded by many an inferior man. No! He made us more tolerant and charitable and hopeful; he helped to keep the heart of society tender and impressible; he loved women and children, and the poor; he loathed the bigot and the fanatic, but never sneered at those who taught humbly and unobtrusively the message of religion; and thus he won a place in the hearts of all who spoke his tongue; and how firmly he had become rooted there, was known to many for the first time when they learned that his work was done."

THE

NATURAL HISTORY OF PAVING STONES.

A LECTURE

BY

PROFESSOR WILLIAMSON, F.R.S.,

Delivered in the Hulme Town Hall, Manchester, February 1, 1871.

DR. ROSCOE, who presided, said:—I have great pleasure in re-opening the series of "Science Lectures for the People;" and I have the more pleasure because my friend Professor Williamson has consented to deliver the first lecture. I am afraid that the title he has chosen has given some people the idea that it would be a dry lecture. I know, however, that all those who are present will not only not regret that they have heard the lecturer, but will feel sorry that they did not bring their friends with them; for, like the giant in the story, Professor Williamson will extract for us interest and benefit even from paving stones.

Professor WILLIAMSON said:—Ladies and Gentlemen,—When, some century and a half ago, the first excavations were made into the lava masses that covered the ancient city of Pompeii, it was discovered that the streets of the city had been paved with blocks of lava from the adjoining mountain Vesuvius. You have probably all heard of Macaulay's apochryphal New Zealander, who, in some future age, when England has passed its zenith, and is once more become a desolate wilderness, is to sit upon one of the broken arches of London Bridge to sketch the ruins of St. Paul's. And if that topographer of the future, when he accomplishes the task that the brilliant essayist assigned to him, visits the city which tradition indicates as having been the ancient seat of manufactures in this part of the country—I mean the city of Manchester—he, if he has assistants with him and should make similar explorations in the streets of this city, will have to record the same fact that has been recorded

of ancient Pompeii. Unexpected as the fact may be even to you, he will have to announce that the streets of the city were chiefly paved with lava from an adjoining mountain.

Now before I demonstrate this apparently paradoxical statement, I must call your attention to the fact, which probably most of you know already, that there are two very different kinds of rocks found in the interior of the globe. There are, first, those that have been produced by volcanic fire—lavas—of an endless variety of sorts. There are, secondly, what are called the stratified rocks, that have been produced by the action of water. If you see a muddy pool depositing layer after layer of mud, and if when this mud subsequently becomes dried up, you proceed to examine the muddy deposit, you will find that it is arranged in layers. Now this deposit is on a small scale an epitome or picture of what is taking place on a gigantic scale in lakes and seas throughout the entire world. Every part of the world has been under water at one time or another; and the deposits that have been produced during countless ages have given us what we call the "stratified rocks." But you will probably like to have a proof of everything that is said from this platform. You may ask—How do you know that these deposits have been formed by water?

I wont dwell upon the subject; I will merely say that where we find oysters and mussels, and cockles, and crabs, and lobsters, we are pretty safe in affirming that the deposits which enclose the remains of those marine creatures must have been formed somewhere in the neighbourhood of the place where these marine creatures lived. And so the marine remains of fossils that we find in these rocks clearly testify to the fact that the rocks in question were formed by watery agency and under water. But you say, in the second place, even supposing we accept that proof as satisfactory, what evidence have you to give us that the other rocks were formed by fire? As this will be the special subject of a portion of my lecture to-night, we will take a little more trouble to demonstrate this fact to you, and make it plain.

The first photograph that I will show you is one from a drawing in a work recently published by Professor Silvestri, a work in which he gives an account of the changes that have taken place during the last few years through the eruptions of Mount Etna. Here you have a view of the summit of Etna; the central peak is here. I need scarcely tell you that you are looking down upon it as if from one of the balloon posts, about which we have heard so much latterly. All these round knobs that stand out so numerously and so prominently are so many craters that from time to time have burst

through that mountain. There are hundreds of these craters, and a large number of them constitute even decent-sized volcanic mountains, scattered round the slopes of Mount Etna. Then these large black spaces, to which I would particularly call your attention, are areas where the lava has burst through some of these craters. Of course it has filled up the crater through which it flowed; but, in addition to filling the crater, it has overflowed its summit, and spread itself out in broad table-like areas over the sides of the mountain, and over the surrounding plains. Now, we have here an illustration of the kind of thing that these volcanic mountains exhibit. You may be somewhat surprised if I tell you that those slopes of Mount Etna are scarcely more pierced by craters and encompassed by deposits of lava than Wales is, in our own immediate neighbourhood. There has been a time when Wales was almost as much disturbed by volcanic fires as Sicily is now. If you were to take a geological map of Wales, you would see that it is studded all over and in every direction with little red spots. Those little red patches are colours employed by geologists to indicate masses of ancient lava. Wales abounds in these masses. We find them on every hand, and it is to some of them, in the first place, that I shall have to call your attention to-night. I will show you a section of a part of Wales where we have volcanic rocks, and stratified or aqueous rocks, side by side, or rather, the one within the other. A section, you will understand, is that which you would have if I were to cut a Dutch cheese in two, and show you the cut side of it. If the Dutch cheese had happened to have been made of layers, piled upon one another like a pile of sandwiches, you would then have the edges of the layers revealed to view. But here, instead of sandwiches, we have a series of layers of stratified rocks; and, in the middle of them we have a great mass of volcanic lava. This is a mass of ancient lava from one of the Welsh mountains, with an unpronounceable name. I dare not venture to utter it. I should only fail; because, as you know, it is not easy to say which are consonants and which are vowels in the Welsh language, unless one is trained to it, which I was not. These are slate rocks. You will observe they are arranged in sloping layers, but these layers were originally horizontal. The reason why they slope upwards is that the volcanic fires which accompanied the outburst of this lava mass has driven up these stratified rocks, tearing them asunder, whilst the lava has forced its way through. We have several reasons for affirming that this lava was once fluid. You will observe that the

lava has not only broken through these stratified rocks, but flowed upwards and downwards in all directions, filling cracks and crevices, which would not have happened had this lava not been fluid. Before I give you another section illustrating to you this action, let me show you a section of Snowdon itself, cut in two. You shall also see the summit of Snowdon, which a kind friend who is in the room has brought to us. Then we have here a section of Snowdon. Here you have the extreme summit of Snowdon—the point to which many of you probably have been. You will observe that there are several series of rocks following each other. Now what, in the first place, are these purple-coloured layers at the base? (The colours are merely conventional, for the purposes of the diagram.) They are beds of slate rocks. These yellow-tinged parts above them represent enormous masses of lava. Now, this mass of lava was once continuous over many miles of district. The reason why it is now isolated is this: after spreading over many miles of district, it has been subjected to the action of currents of water when the whole was under the sea. These water currents have scooped out deep valleys, and swept away an incalculable number of square miles of solid materials. Parts of Wales that were once thousands of feet higher than they are at the present day, have been completely cleared away by this watery action—by what is technically called "denudation." This accounts for the interrupted character of these masses of deposit. The summit of the mountain is a mass of volcanic product, not lava, but ashes. It would appear as if the volcanic outbreak which had covered this part of the country with this peculiar kind of volcanic rock, had been followed by some outburst such as you meet with in volcanoes of the present day, in which an enormous quantity of volcanic ash has been deposited; and some of what escaped removal by denudation now constitutes the extreme peak of Snowdon. The next picture will show the peak of Snowdon as it now is. The difference between the present and the past is very considerable. I do not mean to say that the cairn is a volcanic peak; it is not; but the material upon which the wonderful cairn is erected is volcanic; it is made up entirely of volcanic ash. So that we have in Snowdon three distinct masses of material—the volcanic ash at the top; a mass of lava in the middle; and the water-derived slate rocks at the base. In the diagram I showed you just now, you saw a broad red band crossing the picture obliquely. Now this band is another kind of volcanic rock, and of more modern date than the

others. You ask, "How do we know that?" Well, I think we may safely venture to say that that which goes through another thing, has come there subsequent to the time when that which it penetrates first existed. These rocks, you perceive, have been already deposited when some huge volcanic crack has been formed in them, and volcanic material has come up and filled that crack. Here we have evidence of successive outbreaks of volcanic action. Now I will show you the proof that this volcanic action was accompanied by heat. I think I have said enough to show that this material must have been fluid. The reasons why we conclude that that fluid must have been in a heated state like lava, are these. In the first place, wherever the lava has come in contact with any other kind of rock, it has entirely altered the character of that rock. If it has come in contact with coal, it has burned that coal into cinders; if it has come into contact with limestone, it has burned that limestone into marble; and if it has come into contact with slates, it has altogether altered the character of those slates, and given them a different appearance. I will show you an instance proving this point. The picture that I am now going to exhibit to you is a section of another part of Wales, derived, as most of these sections are, from the very able report on the Geology of Wales by Professor Ramsay, and which was published in the Memoirs of the Geological Survey of England.

Here we have a series of slate rocks with a dyke of lava running through them. Here is a fragment of slate torn off from these rocks and embedded in the lava. You will observe that the appearance of the slate immediately above and below the lava is altogether altered. The difference is this—one portion of the slate cleaves easily into roofing slates; but the layer in immediate contact with the lava has been so altered by that contact that it refuses to be so cloven. Now you have here a clear proof that the contact of the lava with the stratified or aqueous rocks has made an entire change in the structure of those rocks; and we know from examination that all these changes, wherever we find them, are precisely the phenomena that would result if the same rocks were exposed to the action of heat.

The next point that I will speak of is the more special subject of the lecture to-night. I am going to tell you about paving stones. As Professor Roscoe has intimated to you, it is a somewhat unpromising subject; and I confess I was rather disposed to approach it with a little fear and trembling. In Manchester, as I learn from our friend Mr. Stott, who has charge of this department, we use different kinds of stones for paving. I have here

three stones of one kind, and several stones of another kind. Before going into details, I must remind you that we have in Manchester an ancient civilisation and a modern civilisation. If you go along the back streets of Ancoats and other parts of the town, it will be desirable, especially if the day be wet, to take care to have thick shoes, because walking in thin shoes on the rounded boulder stones with which those older streets are paved is somewhat uncomfortable work. But our civilisation has made our more modern streets very different. You know that they are paved with those square stones which I think are technically call "sets," stones which make a magnificient paving. The only complaint we hear about them is when our authorities do not supply the streets with quite sufficient water, and then the gentry who ride their horses or drive their carriages are a little disposed quietly to complain. But this is only one very insignificant feature of these stones. It is true they are apt to become a little slippery in dry weather; but on the other hand, they are exceedingly durable, and being durable they are eminently fitted for the purpose of the tax-payer, whatever they may be for the equestrian. I learn from Mr. Stott that we obtain these "sets" from three localities. Here is one stone that is obtained from Penmaenmawr. Here is another stone that has been obtained from the Clee Hills in Shropshire; and here is a third stone that is obtained from a part of Carnarvonshire, from the neighbourhood of a place they call Glynnog. What are the rocks at these three localities? The Penmaenmawr and the Clee Hill stones are very similar in their essential qualities; they are lavas, closely allied to the forms we commonly call basalts and greenstones. I wont enter into the minute distinctions of these stones. I am not about to bewilder you by the wonderful chemical formulæ that my friend behind me (Dr. Roscoe) could favour you with, in describing the chemical composition of these stones; that would be out of my reach and line. Neither will I trouble you much with minute distinctions between one kind of basalt and another. There is an endless series of these distinctions that would perplex any philosopher to define, and it would perplex him still more to identify all the varieties when he saw them. All I have to do with them to-night is to say that there are many kinds of lava, whether we choose to call them basalts or greenstones, or felspars or porphyries, or by any other of those mineralogical names which are employed to distinguish them. But we can draw a broad distinction between basalts, an ancient kind of lava, and granites, which are also an ancient kind of lava, but a very different one. Let us see what this Penmaenmawr stone is.

It is a lava very similar in its essential composition to the lavas of modern times. Let us see what sort of appearance these rocks present as seen in a photograph. I have here two photographs of Penmaenmawr, a place that probably many of you have visited. One is a view from the north side, and the other a similar view from the south side. Here you have Penmaenmawr as it appears from the south side.

You observe that we have here a sloping plain. Now this plain consists chiefly of stratified rocks of various kinds. But you notice that Penmaenmawr is a huge rocky mass that rises up out of the plains—a huge boss. Now, let us see the other side of Penmaenmawr. When viewed from the opposite side, it presents precisely the same features as before. Here you have Penmaenmawr as seen from the village itself. You observe that from this side, you again have a large plain, made up of stratified rocks, with this immense boss of lava that has been forced through from below. The section I am about to show you is from the very heart of a mountain called Mynydd-maior. It consists of substantially the same rocks as Penmaenmawr. Now notice the stratified rocks. They have been thrown into almost vertical positions by the outburst of this lava. When the denuding currents have swept over that country—as I have told you they have done, again and again, through countless ages—they have removed all those portions of the rocks that were softer than others; they have yielded to the action of the water, whilst the harder rocks have resisted it. Now this lava being harder than the stratified rocks, has resisted that action; and, therefore, it stands out like a huge boss from the surrounding plain, precisely in the same way that we have seen that Penmaenmawr stands out from the plain surrounding it. It is simply because this crystaline lava is very much harder than the rocks around it that it stands in this fashion; it has resisted the denuding action; the other rocks have yielded to that action. Here then we have a clear illustration of the nature of the rock of which Penmaenmawr consists, and which we are using to a very considerable extent for the purpose of paving the streets of Manchester. We will now leave Penmaenmawr.

Let us next see what we have got in the Brown Clee Hills. Mr. Stott informs me that the Clee Hills stone will serve our purpose better than the Penmaenmawr stone. He believes it to be a harder stone. But when we examine the conditions under which it was formed, we discover that it is substantially the same thing we have had before. Here you have a section of the Clee Hills. At the base we have a limestone, similar to that which

you have in the hilly districts of Derbyshire. Then we have here the millstone grit—that coarse grit—stone found in the hills behind Oldham and Rochdale. Then, at the upper part, we have a coal field, furnished with seams of coal like those that we find in this neighbourhood. But this red band running up through the centre of the section, and overflowing right and left, is really lava, very similar to what we have seen at Penmaenmawr, a crystaline basalt, which is spread out over a very considerable area, forming an extensive moorland district; and it is from this district that this Clee Hill basalt is now being brought to Manchester. Thus we see that the phenomena attending the formation of this Clee Hill basalt are precisely the same in all essential features as those that have attended the formation of the basalts in Wales.

We have now to look at the third stone. You are all more or less familiar with the name of granite. Granite has unquestionably been an ancient lava; but it has been rather different from modern lavas in a variety of secondary circumstances. We see very clearly, first from its composition, and second from its microscopic structure, that it has not been formed under the same conditions as the ancient lavas with which we are familiar. The probability is that it has been formed under greater pressure. Whether that pressure has taken place deep in the interior of the earth, or whether it has taken place, as some suppose, under a deep ocean, we have no means of knowing. But there are many minor and secondary features about it which indicate that the conditions which make granite different from other stones, have resulted from an enormous pressure. But then we have two kinds of granite. Common granite is made up of three minerals, known by the respective names of quartz, mica, and felspar. But the particular variety which I hold in my hand, is that known by the name of syenite; and it differs from other granite inasmuch as the mica of ordinary granite is replaced by the crystals called hornblende. This is not a matter of any very great consequence to us, except for this reason, that the hornblende being somewhat harder than mica, we may fairly expect that the syenite may give us a harder paving stone than the ordinary granite. We will see what this syenite is like when at home. Here is a section which exhibits to us the locality from which this syenite is obtained. In it we again observe that we have the stratified rocks thrown upon end. The fact is, these stratified rocks, in Wales, as elsewhere, have been twisted and twined about almost as easily as you could twist and twine about

layers of cloth or brown paper. The forces with which nature has altered the conditions of these strata, have been so gigantic that any resistance these rocks could afford has amounted to very little indeed. This syenite, you observe, presents itself to us under precisely similar conditions to those we have seen in the case of basalt. It comes up from below, filling a huge crack; and if we examine the sides of the crack we shall discover that the heat of the fluid mass of syenite has altered the rocks, just as the basalts and other lavas altered the stratified rocks.

We will now leave these "sets" and examine an altogether different branch of our subject. We must turn to the ancient Manchester paving, and this brings us to the boulder stones. We have to take into consideration two or three circumstances in connection with these boulder stones. I am informed by Mr. Stott, that in the olden time, when we were in the habit of importing boulder stones for all the streets of Manchester, they were chiefly brought from the sea coast of Cumberland. If you go to the sea coast, either of Cumberland, or of any other land, you will find that it is frequently made up of rounded stones, anything but agreeable to walk upon; almost worse, if possible, than the rounded stones with which your older streets are paved. You might be disposed to imagine that all these rounded boulder stones had tumbled down from the cliffs above, and simply been rounded by the action of the water, by the waves beating upon them year after year and century after century. And in the case of many of these boulders you would undoubtedly be right in so surmising. I don't know much about the Cumberland coast, but I could take you to the Yorkshire coast, about which I do know something, and could show you there precisely similar phenomena to those which appear on the Cumberland coast; and we have every reason to suppose that the essential conditions are pretty much the same in the two localities. When we visit these coasts, whilst we discover a large number of rounded stones derived from rocks forming the adjacent cliffs, we also discover mixed up with them a very large number of stones that are not to be found *in situ*, as we call it, that is in their natural position, within miles from us. Here, then, we clearly have to seek out some agent that has assisted the sea. There has evidently been some other power at work that has brought boulder stones to that Cumberland coast that were not there originally, and that were not derived from the strata of the adjoining cliffs. We find there granites and lavas, and an endless variety of other rocks that were not originally

derived from the Cumberland hills at all; they have been imported into that district and subsequently re-imported from that district to Manchester. Now whence have these other stones come? It will simplify the matter, as the Irish song says, "altogether entirely," if we call your attention to a Manchester brickfield. You may ask, what on earth can a Manchester brickfield have to do with Cumberland boulders and the paving of Manchester streets? More than you would imagine at first sight. If I take a walk with you to a Manchester brickfield, we shall discover that we are most interested in precisely that part of the field that will be the greatest abomination to the brickmaker. The brickmaker likes the nice, smooth, soft clay, without any stones in it, which to the geologist is about as stupid a part of the field as he could have. The geologist, on the other hand, likes to find a place that is full of gravel and sand, and huge boulder stones of every shape, and sort, and size—the very abomination of the brickmaker. I have here certain boulder stones that were taken from a Manchester brickfield. What have I in my hand? A block of granite, which I carried painfully and laboriously one day from a brickfield in the neighbourhood of Ladybarn. It is a mass of granite, rounded just like the rocks on the Cumberland coast. That granite has been transported from a considerable distance, because we have no granites nearer than Cumberland. The nearest granite we have to this locality is that of Shap Fell, in Cumberland. The granite from Shap Fell is a very remarkable granite, from the large crystals of flesh colour which distinguish it. I have here, from this same brick-yard, a piece of Shap Fell granite. Why, I could swear to this piece of granite all the world over, as a man would swear to the face of his own wife wherever he met with her. The features of it are so remarkable that you could not mistake it, if you knew what Shap Fell granite was. Now this Shap Fell granite, rounded and water-worn, has been brought to a Manchester brick-yard. How has it got there? I have here another boulder. There is nothing particular about the appearance of this boulder, except that it is a piece of limestone that never "grow'd"—if I may apply Topsy's word—in the neighbourhood of Manchester. It, like these other stones, has been brought to Manchester from a distance. But it tells me another story. It has another tale to record. I see that this surface is grooved, as if covered with the marks of a file. I turn it round to the other side, and I see that it is filed and grooved in like manner; but these grooves are not parallel with the former grooves. Here is a second flat face. It is very evident that in some way both these faces have had a good scrubbing, that has involved

something more than a mere washing of the face. I dare say we have some keen reminisences of the sort of scrubbing we used to get from the nurse's hands with rough coarse towels; but that is nothing compared with the scrubbing these stones must have had. There has been an action which has flattened that surface and grooved it at the same time. We want some agency that will do all these things together. You will remember that when my friend Professor Huxley lectured here at the beginning of this series of lectures, he pointed out to you in a very clear and prominent manner, how absolutely necessary it was that any theory that was propounded to explain a multitude of phenomena should "go upon all fours;" that is, it must be equal to the explanation of all the several isolated and detached facts that the theory is intended to explain. Now we want a theory that will explain all these things. We want a theory that will mix together rocks of all kinds, that will mix them up with clays and with sands, and with an endlessly varied set of materials. We want a theory that will make some of these rocks round and grooved and streaked. We want a theory that will explain why some rocks that are transported are as angular and as sharp as this specimen. In order to give you such a theory, I shall have to carry you half way across Europe. I will begin by taking you to Switzerland, and if you have as pleasant a voyage thither to-night as I had some months ago, I shall envy you the repetition of my enjoyment. Here is a photograph I took in one of the loveliest scenes in all Switzerland. Here you have the Mer de Glace, that great stream of ice which has been celebrated in almost all ages as one of the loveliest spots in Switzerland. The Mer de Glace belongs to that range of mountains of which the peak of Mont Blanc is the centre, and it is only a few miles away from that great mountain. This is a glacier. What do we mean by that? Those mountains which you see on all sides of the glacier are within the limits of perpetual snow; summer and winter, wherever there is a ledge upon which the snow can rest, it remains unmelted. This accumulation of the snow would in time entirely hide and bury the mountains, unless nature had provided some way for getting rid of the surplus. She has provided such a way. The pressure of the snowy mass on the upper parts, forces the lower snow down into the valleys. Then that snow, partly under the influence of the intense cold, and partly under the influence of the pressure to which the particles are subjected, becomes re-frozen, becomes consolidated, not into snow, but into a mass of solid ice; and by a wonderful series of changes, which my time will not allow me to explain, this icy mass

flows down the valleys of these alpine mountains, fitting itself to the various curves, to the widenings and narrowings of these valleys, almost as if it were a fluid. Indeed, so wonderful has been this peculiar power of the ice to adapt itself to the shape of the valleys, that the late Professor James Forbes, of Edinburgh, arrived at the conclusion that ice, hard as it appears to be when you are skating over it, must have possessed a certain property of viscosity, a certain kind of fluidity, which enabled it to adapt itself to the various contours of the valley. Professor Tyndal, however, has given us a better explanation. He shows us that this downward steady movement is really accompanied by a crushing process, instantaneously followed in each atom by what he calls re-gelation, which means in plain English, freezing over again. The point we have to deal with is not this re-gelation. We may take the movement of the glacier as an accepted fact. These glaciers move from the higher valleys into the lower ones at a very slow pace, but one which is capable of being measured. But what takes place as they do so? These magnificent mountain peaks, composed in this instance chiefly of granite, are being continually disintegrated by the cold of winter, by the rain, storms, and various atmospheric agencies that affect the surface of the globe. Huge fragments come tumbling down from above, and of course these fragments fall from the ice. You will see running along here a band of rubbish that has fallen from above. You will see along here another band of rubbish that has fallen from above on the opposite side. The next photograph is one I took of the same spot, in the immediate neighbourhood of what is called the *moraine*, or, in other words, this band of rubbish. Here you have the mountain slopes that we descended. We crossed over these huge rocks. Here you see the ice-slope which we had to climb in order to get upon the glacier. You see here what kind of materials the moraine consists of. The whole of this mass of rubbish is resting, not upon the ground, but upon the ice, so that, as the ice moves, it carries all these rocks along with it, just as easily as you would carry your hat upon your head, and if it is one of the chimney-pot hats, I venture to say an enormous deal more easily! This is what is called a lateral moraine, one running down each side of the glacier. There are other moraines. The next photograph that I will show you is from another glacier in the Chamouny valley—another of the Mont Blanc glaciers—but it shows a different part of the glacier. This is a very instructive picture to those who have not visited the real scene. Here is the lowermost part of the ice; here is the

cavern from which the water issues—there is always a torrent of water rushing down—and here we have what is called the terminal moraine. You will understand that when these masses of ice come down from the cold valleys above into the warm valleys below, the ice necessarily melts. Were it otherwise, those splendid scenes would become simply one sheet of polar ice. It melts, but the stones that it carries wont melt; consequently they have to stay there. As the ice melts, these stones drop down; and here you might almost imagine that you see them in the very act of dropping. These are stones that must have fallen almost the very day that I was there. Here is a glacier covered with ice; here are all the stones that form the moraine; here is the melting ice breaking off in blocks; and, as the ice breaks off and melts, the stones that break off with it tumble down as you see here. Now, you observe that in this way we have brought down to the lower valleys enormous quantities of material that lately had their home on the peaks of the mountains and in the valleys above. In this way we see that the glaciers not only receive from the mountains on each side immense masses of rock, but that they carry these masses of rock along with them down to the lower valleys. There is no doubt whatever that a very large quantity of material that we now find spread over the surface of the globe has been conveyed in this way.

But this alone would not account for the phenomena of our Manchester brickfields. We want something more. We have evidence clear as the sun at noonday, that the material of which our Manchester brick fields, and the brick-clays over a great part of the world are similarly composed, have been brought thither by water. They have been deposited under water. We frequently find sea shells in them. We have the clearest evidence, I repeat, that these remains have been accumulated under the sea. Unless we can bring our glaciers in some way into contact with the ocean, our theory will not fulfil Professor Huxley's requisition—it wont "go upon all fours." Let us see if we can find proof of that contact.

We will now transfer ourselves from Switzerland to Smith's Sound, in the Polar regions. Here is a drawing I have copied from one of Dr. Kane's sketches. Here you have what is intended for the sea. If you saw it in daylight, it would be a proper sea green. Here you have the rocks and lofty cliffs that surround the part of the country in which the phenomena I am about to explain exist. In the extreme winter these masses of ice extend right across the Sound, from side to side. As the summer approaches, the central ice breaks up speedily, and floats away; but long belts of ice

hold their ground around the coast for a considerable part of the year, and sometimes they fail to break away from one season to another. Now these blocks, or masses of ice, technically called "ice belts"—because they belt round the coast—receive masses of rock in precisely the same way as the glaciers did in Switzerland. Thus we see that these blocks of ice would carry away with them blocks of stone, if any circumstances occurred to detach the ice from the land. The detachments take place perpetually, and they carry away with them these blocks floating upon their surface. They are hugh ice-rafts, which sail southwards, impelled by Arctic currents. But this is not all. We have some glaciers in these polar regions, of precisely the same nature as those of Switzerland; but, instead of the polar glaciers being comparatively diminutive—a quarter, or half a mile across—the great Humboldt glacier is 50 miles across, from one side to the other, and yet that Humboldt glacier, which comes right down into the sea, is bringing stones along with it in precisely the same way as the other glaciers. Now, with such prodigious masses of stone-covered ice as this existing in the northern seas, you will not wonder that from time to time icebergs of the most gigantic size are met with, floating out of those northern bays and straits. Remember that what are called icebergs are merely either fragments of this belt of ice of these Arctic glaciers broken away, or portions of that huge mass of ice which in winter covers the whole of those regions—when you see that these ice formations exist on so gigantic a scale, you will not wonder that icebergs are met with in these seas, sometimes a mile in extent. If you realise that, when you have an iceberg of this size, it floats with its summits two hundred or three hundred feet above the sea, and that it sinks below the water, some six or eight times its elevation, I think you will readily understand how that floating raft would be able to carry a very considerable slice of Penmaenmawr upon its surface! I have here a picture of one of these floating rafts copied from Dr. Kane's book. I have represented it as well as I could. Here you have the ice, which has upon its surface huge blocks of solid rock. This was sketched by Dr. Kane as he saw it floating away into the southern regions. It is an exaggerated example; we do not usually see the rocks so huge in proportion to the size of the raft, but it will give you an idea of the kind of transporting power that these ice rafts have.

Now let us see how all this applies to English scenery. I have told you that the glacier moves steadily down the valley. You saw from the diagram that the glacier is cut up by

deep fissures, called crevasses, that go down frequently to its very bottom. The stones that appear upon the surface of the glacier fall into these crevasses, and at the bottom they become entangled in considerable numbers in the solid ice. Many of them are angular. But you will also understand that if that vast mass of ice, filled with stones, is moving steadily downward over the rocks of which that valley consists, those stones will act like the teeth of a huge rasp; that they will plough, just in proportion to their size and sharpness and hardness, deep grooves in the rocks along which the ice is travelling. The stones themselves, being imbedded firmly in the ice, will scratch and scour over the rocks over which they move; and this is precisely what we find that they do. Sometimes the ice retreats, leaving behind the smooth and polished rocks, over which it formerly travelled; the changes of the seasons frequently lead to its doing so; the glaciers not unfrequently recede up the valleys in hot seasons and come down again in cold ones. When the ice recedes we see that the rocks are scored and grooved and polished in the way we should expect them to be. But if they receive this rough sort of treatment, what might we expect to be the result upon the teeth of the rasp? Workmen know perfectly well that when they use their files upon hard metal the angles get worn off. It has been so here We could readily understand that if this stone was embedded in the ice, and formed one the teeth of our great Arctic rasp, that its surface might well be flattened and grooved with longitudinal grooves. Here, then, we have an agent capable of producing grooves. Then, if these icebergs float upon the ocean, carrying rocks with them, they will travel southwards, carried by currents, and, as they come into warmer regions, they will share the fate of the Alpine glacier. Floating upon the sea does not save them; they melt little by little, and as they melt the rubbish that they are supporting falls to the ground. The fact is, we have here a grand Arctic Limited Liability Carriage Company! and it is one in which the liabilities, in a financial sense, are at a minimum and exceedingly small, whilst the transporting power is at its maximum, or exceedingly great. If we were shareholders in a limited liability company, these would be just the results that we should like to attain to if we could. Inasmuch as the floating rafts cost nothing, it is of no consequence to the company that they melt, and that whatever they carry goes to the sea bottom If they were bringing our trunks from the Arctic regions, we should find out the difference between them and a good old wooden ship. But they melt, and whatever they sustain, trunks or stones, goes to

the bottom. The result is that large portions of the sea bed are being strewed over with blocks of stones—angular blocks, rounded blocks, sand, rubbish : every conceivable kind of produce that those northern mountains furnish is being gradually brought southward, and scattered over the bed of the Atlantic at the present day. And precisely similar phenomena were taking place during one of the latest of the geological periods when nearly the whole of our island was under the sea. There was a time, comparatively recent, geologically speaking, when our island was under the sea, but when the mountains of Wales and Scotland stood out like islets from the Arctic ocean. The great valleys of Snowdon were filled with these glaciers. If you go up the Pass of Llanberis, you will see on every hand the indications of the fact in the rounded rocks, and in their scored surfaces, that abound on each side of the road. A little above the village you see them beautifully exhibited; and in the same way, throughout in the district of which Snowdon is the centre, you have these indications of glacial action so numerous and so clear, that not a shadow of a doubt remains that the Snowdonian valleys, as well as the valleys of Cumberland and Scotland were, at the time of which I am speaking, filled with ice glaciers. Now all these glaciers—along with others coming from hundreds not to say thousands of miles away, as well as from mountains in the immediate neighbourhood—brought their produce to the same bed of the ocean, and as it was all tumbled down into one common mass, you find materials in the shape of mud and sand as well as coarser materials, including both rounded and angular blocks, accumulated in the same sea bed. Now I think you will see that I have brought before you an explanation that fully accounts for the miscellaneous kind of admixtures that you find amongst the sand, and clay, and gravel beds whether of a Manchester brickfield or of the coasts of Cumberland and Yorkshire.

Ladies and gentlemen, I have now finished my task. I have endeavoured, I trust not altogether unsuccessfully, to show you that in the natural world there are no objects, however common and familiar, that cannot reveal an interesting story, if we are but intelligent enough to question nature in a right manner. Many of you are occupied with manufacturing pursuits, and, from time to time, your workshops receive the visits of strangers, who look with intelligent interest upon the processes in which you are engaged, and upon the final products of your labours. I invite you, in like manner, to visit nature's workshop. She, too, is a fellow-labourer with yourselves; only, unlike you, she needs no

rest, but works on, with untiring energy, day and night, summer and winter. She usually toils so noiselessly that few men know the vastness of the forces at her command. When we float idly upon a summer sea, or recline in some sheltered nook, watching the tranquil glories of a July sunset, we reck little of the fearful energies that underlie the present calm. It is only when Nature rouses herself, like some angry lion, that men recognise her terrific powers. It is when the reeling earth is shaken by the earthquake, and cities crumble into dust; when the volcano belches forth its showers of ashes and streams of liquid fire, hiding the prostrated ruins from the eyes of men; when the flashing lightnings and the grand roll of the thunder inspire the stoutest hearts with wonder not unmixed with awe; when the stormy ocean and the flooded river inundate the land, tossing man's proudest works, like playthings, from their surface, and hurling them to destruction, then it is that we learn something of Nature's power. Yet these forces, at times so terrible, are ever working out their Divine Creator's will and ministering to human wants. Study them and they will interest you; examine their products and they will repay you. You will then recognise the truth of the words which our greatest dramatist puts into the mouth of his banished duke, when he declares that there are

> Tongues in trees, books in the running brooks,
> Sermons in stones, and good in everything.

On the motion of Mr. JOHN PLANT, F.G.S., thanks were given to Professor Williamson for his interesting lecture.

THE

TEMPERATURE AND LIFE OF THE DEEP SEA.

A LECTURE

BY

DR. W. B. CARPENTER,

Delivered in the Hulme Town Hall, Manchester, February 8, 1871.

DR. CARPENTER, on being introduced by the Chairman, said:—Ladies and gentlemen, until a recent period the bottom of the deep sea has been—if I may make use of an Irish "bull"—an unknown land to us, for the means of research into its condition were very unsatisfactory. For example, in the first place, with regard to temperature, if we let down a self-registering thermometer, which should give the lowest or the highest temperature which is there encountered, there is this source of error in the indications of the thermometer—that the enormous pressure of the water upon the glass bulb will very probably so alter the shape of the bulb as to force up the mercury in the tube. Now it has only been recently, through the ingenious contrivance of my late excellent friend, Professor Miller, of King's College, that this difficulty has been overcome. We found on putting thermometers of ordinary construction into the machine which is well known to many of you—a Bramah Press (I don't mean between the boards of the Bramah Press and squeezing them between two solid masses)—but putting them into the water chamber of an instrument constructed on the principles of the Bramah Press, with a powerful force pump that should subject these thermometers to pressure of any amount up to three tons to the square inch—we found that the very best thermometers that had been previously relied upon were raised from eight to ten degrees by the pressure of the water forced in; and we found that inferior thermometers, such as had been used in many deep sea soundings on former occasions, were raised from twenty to fifty degrees. So that you see there is no reliance to be placed upon any previous deep sea soundings as to temperature, except in this, that we know that the error of their thermometers could not have been *less* than a certain amount. For instance, when Sir James Ross and his companions carried on their deep soundings in the

Southern seas, and found, as they very often did, at a depth of from 1,500 to 2,000 fathoms, that their thermometers indicated a temperature of 39 or 40 degrees, we know now that the smallest error of their thermometers being eight degrees at that depth, the true temperature could not have been higher than about 32 degrees—that is about the freezing point of water. Now the means which Professor Miller suggested for overcoming this difficulty were extremely simple. It was merely to enclose the bulb of the thermometer in an outer bulb, sealed round the neck, a space being left between the two bulbs. Now that space was not left entirely empty; it was about three parts filled with fluid. You may ask, Why was the fluid introduced there? For this reason,—if only air had been left in that space, the inner bulb would have been a very long time in taking the temperature of the water round the outer bulb; and the air being a bad conductor it would have been necessary to allow the thermometer to remain perhaps an hour before the mercury or spirit of the inner bulb would have taken the temperature of the water outside; but by introducing between the bulbs some spirit, that spirit conveyed the heat or the cold from the outer to the inner. Still it was not filled with the spirit, because if it had been filled the pressure upon the outer bulb, and its consequent change of form, would have acted in the same manner upon the inner bulb; but there was a void space left, and therefore the changing of the form of the outer bulb by the extreme pressure produced no alteration in the shape of the inner bulb. We subjected thermometers, which we thus protected, to the pressure of three tons to the square inch; and we found that they did not rise more than about one degree, and that small rise was really due, we have reason to believe, to the increase of heat in the liquid occasioned by the pressure to which it was subjected. That is the mode in which the thermometer has been adapted to the purpose of obtaining the temperature of the deepest ocean waters; and I shall show you what very important information we have derived from its use.

The pressure which is caused by a column of water of course varies with the height of the column—that is to say, with the depth of the water; and in round numbers we may say that at 800 fathoms—a fathom you know is six feet—the pressure of a column of water is one ton upon every square inch; therefore, at 2,400 fathoms,—which was about the greatest depth to which our soundings extended (and I may just remark, in passing, that my friend Sir Wm. Fairbairn has a little under-estimated the work that we did, for we not only sounded but dredged at nearly

three miles depth—2,435 fathoms)—at that depth the pressure is just three tons to the square inch, and that is just the pressure to which our thermometers had been tested. Therefore we know that we had within a degree (we always used two thermometers) the real temperature of the bottom of the ocean. Now I shall show you what very curious and important information we derived from ascertaining the temperature, not only of the bottom of the ocean at different depths, but also of different portions of the column of water in going down to the bottom;—this we ascertained by letting down our thermometers to a certain depth, not letting them go to the bottom, and then taking them up; then letting them down to a greater depth; and so on. In that manner we got what I term "serial soundings"—that is, a series of temperatures of different depths in the same spot; and those corresponded very closely indeed with the bottom temperatures that we got at like varying depths. As a rule, the lowest temperature was always the bottom temperature. I shall presently explain to you how this comes to pass.

Our first expedition was a very short one. We had very bad weather in a very stormy region, between the North of Scotland and the Faroe Islands, and we were not able to make many soundings or many dredgings; and yet, by a piece of extraordinary good fortune, the temperatures of the soundings that we obtained were more curious than any we have obtained since; and they suggested to me a general doctrine in regard to oceanic circulation that all our subsequent researches have tended to confirm. The general facts of the case you will see by this map and the table by the side of it. Here is the North point of Scotland, the Orkney Islands, and Stornoway, the little port of the Hebrides, from which we started. Here are the Faroe Islands. This dotted line is what is called the "hundred fathom line,"—that is the line which bounds that curious platform, so to speak, of which the British Islands constitute the highest part. All around our islands, uniting Great Britain and Ireland, uniting also the Shetland Islands and the Orkneys, the Isle of Man and the Isle of Wight, uniting the British Islands with the Continent of Europe, is a platform of not more than 100 fathoms below the surface. If there were an elevation of 600 feet, Great Britain and all these islands would be joined to the coast of Holland, Belgium Norway, Denmark, and France; there would be no British Channel, or Irish Channel, or North Sea, for nowhere does the depth of water in those parts extend to more than 100 fathoms. But when we get outside this, the water deepens very rapidly. For

instance, here, between the North of Scotland and Iceland are the Faroe Islands; and that dotted line around them represents shallow water, which is under 100 fathoms. Now between this and the Shetland Islands is a deep channel of about 600 fathoms, which is a depth nearly equal to the height of Snowdon. Our soundings in the first expedition were made along this line, where we found, as you will see by the table, very low temperatures, such as 33, 32.2, and 32 degrees. But at the like depth in another part of this channel, the soundings, as marked in the upper part of the table, show a temperature of 45 to 48 degrees. Here was a very marked and curious contrast; for, within a short distance of each other, in one instance only 20 miles apart, we found two very different climates at the same depth.

Now the existence of these two very different climates showed itself, when we carefully worked it out afterwards, in two very distinct kinds of animal life, and two very distinct kinds of deposit on the bottom of the ocean. I will now show how our next year's work in the same region filled up and completed this inquiry, and gave us some very curious points in addition. You may imagine with what interest we went over this ground again, provided with our superior thermometers; for the first year's work was done with the old thermometers, only the depths were not so great as seriously to interfere with their performance; and you will observe that whether those thermometers had been in error or not (and we did not know till we tried) at 500 fathoms, the same effect would be produced in raising the mercury at 500 fathoms, whether it was in a hot or cold area; so that the *difference* of the warm and the cold—between about 32 and 48 degrees—would be just the same. If these thermometers were a couple or three degrees too high—which they proved to be—then we found that the temperature of the first year, which was 32, became 30, and that which had been 48 was really 46. But the difference of 16 degrees was exactly the same; and all that was perfectly verified in the very careful and very numerous and elaborate inquiries which we prosecuted over this area the next year. Again, we took what I have called "serial soundings;" that is, we let down our thermometers at different depths, for instance at 50 fathoms, then at 100, then at 150, then 200, then 250, and so on every 50 fathoms; and the results we got are shown in this diagram, which is so constructed that a curve indicates the descent of the thermometer, and the depths are expressed by the horizontal figures, which run from 50 to 100, 150, &c., marking every 50 fathoms.

In all this area, whether warm or cold at the bottom, we found nearly the same surface temperature—a very curious fact. If we went north it was a little less, and if south a little more; but about 52 degrees was the average. We found that in all parts of this area the descent through the lowering of the thermometer in the first 150 fathoms was the same; and in the warm area when we got below 150 fathoms there was very little more lowering of the temperature. You see that the line in the *warm area* continues nearly horizontal till we pass about 500 fathoms; but from 150 to about 500 fathoms there was very little lowering of the temperature, and we only got it reduced from 52 at the surface to about 45 at 500 or 600 fathoms. But now see what takes place in the *cold area*. This upper line, which at 100 fathoms is but a little below the other, begins to drop rapidly, so that at 200 fathoms it is very decidedly below; and then it goes down still more rapidly, so that within 100 fathoms it dropped about 15 degrees; and all the water in that particular sounding below 300 fathoms was of a temperature below the freezing point of fresh water. The bottom was there struck at 384 fathoms; but in another part we got a much deeper sounding, down to 640 fathoms, which was taken at a point a good deal north: there the surface temperature lowered to between 49 and 50 degrees; it went down much in the same manner as in the other, until it got to 350 fathoms, which was below the freezing point of fresh water, and from that point to the bottom, (640 fathoms) was a river, so to speak, of cold water nearly 2,000 feet deep—below the freezing point of fresh water. Now that was the very curious fact which our investigations of this channel between the Faroe Islands and Orkney and Shetland brought to our knowledge. That channel I have been accustomed to designate the "Lightning Channel," "Lightning" being the name of the vessel assigned to us in our first expedition. That distribution of temperature is indicated on this map. This blue colour represents this cold stream, which could have come from nowhere but the Polar regions; it must have come straight into this channel from the Polar area. But you must bear in mind that though this blue colour represents the water at the bottom, yet the water at the upper stratum of the surface,—that is, for about 150 fathoms—was of exactly the same temperature as the water of the other region around, and that temperature was higher than what may be called the natural temperature of the climate. And thus whilst we had this deep stream of water flowing from the Pole (and we shall presently see what becomes of it)—flowing south-west from the Polar area, we had another stream proceeding north-east of

warmer water—water warmer than the natural water, so to speak, of the latitude, which would have been about 40, and this water had a temperature of 45 or 46 degrees, down to 500 fathoms, and at the surface 52 degrees.

Now, then, what is the meaning of this? When I speak of a "stream" and "flowing," you must understand that there is nothing like a visible movement. I say that this stream must be flowing, because if it were not flowing, it could not retain its temperature; it would soon give up its warmth to the water above. It is quite a physical necessity that it should be in movement; and of course if it is in motion it could only have come from the Polar area to have brought this cold temperature with it, for at the bottom it was about $29\frac{1}{2}$ degrees. You are aware that 32 degrees is the freezing point of fresh water; but it is not the freezing point of salt water. Sea water freezes at about 27; if it is kept very still it will not freeze till 25; and there is a most important difference in the condition of sea water and fresh water as regards temperature below 40 degrees. You all know perfectly well that when such a frost as we have had lately acts upon the surface of a lake, river, or pond, the water freezes on the surface; and if you put down a thermometer into the water below, you will find that it is about 39 or 40 degrees. Now, why is this? You know that the ordinary rule of the contraction of water is that it shrinks, just like the mercury in a thermometer, with cold, and expands with heat. As it shrinks it becomes denser, and therefore heavier, bulk for bulk; consequently when a low atmospheric temperature is acting upon the surface of a pond or lake, the water as it is cooled at the surface becomes heavier and goes down. So it keeps on going down, and fresh and warmer water, which is lighter, comes up to the surface, till the whole is cooled down to about $39\frac{1}{2}$ degrees; but then continued cold does not produce the same effect, for below $39\frac{1}{2}$ the water begins to expand again—(fresh water I am speaking of)—the greater cold makes it lighter instead of heavier; consequently the water which is cooled to below $39\frac{1}{2}$ degrees remains on the surface, and it is exposed longer and longer to the action of the cold atmosphere of the surface until it freezes and forms a layer of ice. Now that is not the case with sea water. Sea water continues to contract down to its freezing point; the more it is cooled the heavier it becomes, because its bulk diminishes; it therefore sinks in proportion to its degree of coldness; and in this manner it is that the coldest water always comes to be at the bottom. There is a very curious consequence of this, for it is a well known fact

that ice in sea water begins to form at the bottom. I do not say it always does, because where ice is once formed on the surface it will extend from the edge of the previous formation; but it is a fact observed by Arctic voyagers, and perfectly well known to Baltic fishermen, that when the season is first changing, and ice is about to form, in the first instance it comes up in little discs or plates from the bottom. The fisherman in the Baltic or in Norwegian Fiords, when he sees these little discs (when out in his boat some distance from land) coming up from the bottom like so many jelly fish, to float on the surface, makes for land directly, for he knows that if he remains he might be frozen up in the course of a few hours. Now that is a very curious difference between salt water and fresh.

This has a most important relation to the doctrine of submarine climate. I have shown you here a sort of little compact pocket edition of a set of phenomena which, as I am now going to show you, prevails over, I believe, the whole of our great oceans. In our soundings a few months ago on the coast of Spain and Portugal, we came upon this fact—the surface temperature was very high, about 65 degrees; in the first 100 fathoms we lost about 10 degrees of this, what we may call the super-heating of the surface, produced by the powerful rays of the midsummer sun. Then the temperature from a depth of 100 fathoms down to 800 lowered very slowly, just as it does in the warm area; so that at 800 fathoms it only got down to 49 degrees. But in the next 200 fathoms, between 800 and 1,000, there was a loss of 9 degrees; the temperature had fallen to 40; in another 100 more it fell another degree, and over the deeper soundings which we took in the previous year, extending down to nearly three miles—that is 2,435 fathoms, a depth about equal to the height of Mont Blanc—we got a temperature as low as 35 or 36; and still lower temperatures have been obtained elsewhere, even under the equator. Thus a temperature of about that was obtained three years ago in the Arabian Gulf, when soundings were being taken preparatory to laying the cable connecting the Red Sea, Aden, and Bombay. Here, then, you see we have in our great oceans a condition just comparable with that which I have shown we met with in the Lightning Channel; first we have a great body of warm water, then we have what I have designated a stratum or layer of intermixture, a stratum between the great mass of warm water above, and the great mass of cold water beneath, nearly down to freezing point. Near the Pole it is quite down to freezing point; but when it is nearer the Equator, where it has had a long

way to flow from the Pole, it will have acquired a certain slight degree of warmth; but still you see, to find a temperature of 35 or 36 degrees under the Equator, shows clearly that that water must have come from either one of the Poles.

Now let us inquire what account can be given of this remarkable phenomenon. Here we have in the deep oceanic basins this layer of water extending more than a mile deep—water which has been obviously derived from the Polar area. What account can we give of it? How does it come to be there? and how does it come to retain its low temperature? Now I think it may be said with perfect certainty that it could not retain its low temperature, unless it was continually supplied from the Polar area. I will show you how this supply takes place. Here, for instance, in this Lightning Channel, we found that we could distinctly trace it along near to the corner of the Faroe Banks; and though we had not the means (I hope we may at some future time have the means) of measuring its movement, yet by the nature of the bottom we felt perfectly sure that it was a running stream, for the pebbles there instead of being angular were round—that you know is a most clear and distinct proof. Well, then, we have every reason to believe that it ran on and discharged itself into the great Atlantic basin. About 100 miles to the westward of this, there was a deep slope, going down to 1,500 or 2,000 fathoms: and this was one of the feeders, so to speak, of this great mass of Polar water in the Atlantic basin. Then between the Faro Islands and Iceland there is a shallow bank; but between Iceland and Greenland again there is a wide and deep channel, through which a very large mass of Polar water will thus come down. Now water cannot be always flowing out of the Polar basin without water from some other source flowing into it; and it is perfectly certain that if there is a circulation of water in this great oceanic basin, that circulation must be maintained by a constant movement of surface water towards the Pole. While the *deeper* water is coming *from* the Pole, there must be *surface* water going *towards* the Pole. You have all heard of the Gulf Stream. There is a great mass of water issuing from the channel between the peninsula of Florida and the Bahama Islands, which is flowing in a north-easterly direction. That very powerful current, issuing from that narrow channel, flows at the rate of five miles an hour in a north-easterly direction, first towards the banks of Newfoundland and the Azores; and then it is popularly believed to flow on towards the northern coast of the British Isles, and thence to Spitzbergen, Iceland, and even

Nova Zembla. Now I have every reason to believe, from careful inquiries lately made, that this Gulf Stream really has not much to do with the phenomena of which I have been telling you, and that its influence pretty much ceases not far to the eastward of the banks of Newfoundland. The Gulf Stream is part of the *horizontal* circulation in the North Atlantic. Now, I think you will easily understand the difference between a horizontal circulation and a vertical circulation. Look at the wind ruffling the surface of a pond. Well, the wind blows the water in a particular direction, and produces little ripples. If it blows away the water, of course water must come in to fill up its place from the other part of the pond. That is a horizontal circulation; and that horizontal circulation in the Atlantic is produced in this way. The trade winds are always blowing between the tropics from east to west; they move along an enormous mass of water, driving it into the Gulf of Mexico; it circulates there, and is excessively heated by the action of the sun, and comes out from this channel in the way I have spoken of, as a rapid current passing in a north-easterly direction. But that rapid current I have strong reason to believe is not a deep current; I believe it is not more than a surface current, and that the heat it carries has been very much over-estimated. About half of it, when it comes to the Azores, or Western Islands, turns round again, goes near the African coast, and returns into the Equatorial current, completing therefore that circulation I have spoken of. The other half goes on past the banks of Newfoundland; there it meets the surface of the Arctic stream, and breaks it up or "inter-digitates" with it—this word expressing an action like that of passing one set of fingers through another. I admit that a portion of the Gulf Stream goes north, but the greatest part is stopped and cooled by this Polar current coming down. It is known that the Polar water lies underneath the Gulf Stream, for if you send the thermometer sufficiently deep you will find the Polar water running beneath this extraordinary surface current.

I have adverted to the Gulf Stream, because I want to show the important influence of this upper movement of warm water, of which I have spoken, which is quite independent of the Gulf Stream. Suppose that the narrow peninsula of Mexico, or the narrowest part of it, which is the Isthmus of Panama, that connects North and South America, were broken through—which it will be in course of ages by the action of the sea—so that there was a free course given to this Equatorial current; it would go right through into the Pacific Ocean,

and we should have no Gulf Stream at all. Even in that case I believe our climate would not suffer so much as most persons believe; because though we should lose a large portion of our warm south westerly winds, this constant flow of warm water which is taking place in the whole mass of the North Atlantic, from the southerly area directly towards the north and north-east, will supply its place; and I am very strongly convinced that the amelioration of the climate of the Polar area is due, not so much as is commonly supposed, and quite recently very ably argued—to the Gulf Stream, but to this great mass of water moving northwards in this slow and uniform progression, carrying a temperature which, taken altogether, is very much greater than that of the Gulf Stream. For the last we know definitely of the Gulf Stream shows that it is thinned off to a layer of certainly not more than 50 fathoms, and perhaps less, and reduced to a temperature of about 55 degrees; whereas this great slowly-moving mass of water carries a temperature higher than the temperature of the latitude down to 500 or 600 fathoms depth, and as the surface is cooled, warm water from below will come up to take its place; and in this manner will carry into the Polar area a great body of heat, so to speak, derived from the general surface of the temperate and tropical oceans. And this I believe has taken place in all geological periods, quite irrespective of any such local accidents as those that produce the Gulf Stream. There must have been in all Geological periods a movement of this warmer water from the Equatorial towards the Polar area, and conversely (and this is most important geologically) a movement of cold water in the depths of the oceanic basins, bringing with it, as I shall presently explain, the characteristic animals of the Polar climate.

But you will ask, and very properly, "What evidence have you of this movement?" and "What produces this movement?" Now, the evidence of the movement I have given you. The evidence of the movement is in the fact that cold water could not remain cold water at the bottom of these oceanic basins, if the supply were not kept up from those cold basins at the Poles. I will give you an illustration. We were at work this last summer in the Mediterranean, and we found the condition of the Mediterranean most curiously different in regard to temperature from the condition of the Atlantic. The Mediterranean is a basin which, to use a Scotch word, is "self-contained." (You know that houses in Scotland are usually built in "flats," which are occupied by different families, and a "self-contained"

house is complete in itself. I daresay that many of my auditors are Scotch, like our respected chairman, and will understand what a "self-contained" house means.) Well, the Mediterranean is a "self-contained" basin; it is shut in entirely, the Strait of Gibraltar being its only communication with the outside; and that Strait is so shallow at its outlet that no communication between the deep water of the Mediterranean and the Atlantic can possibly take place. The Mediteranean goes down in some parts to a depth of 2,000 fathoms; we ourselves sounded to above 1,700, that is from about 11,000 to 12,000 feet. Well, we found the surface very hot; we were there in August and September; the temperature of the surface of the sea rose to 78 degrees in some instances. But very curiously that hot temperature was limited to a very shallow layer indeed; we lost 10 or 15 degrees of that heat in 30 fathoms; at a depth of 30 fathoms we found the temperature perhaps 63 or sometimes as low as 60 degrees. Then a further loss of temperature would be experienced in going down to 100 fathoms. At that depth we came almost invariably to 54 or 55 degrees; and whatever was the temperature at 100 fathoms, that it was down to the very bottom; depth there made no difference at all; if it was 55 degrees at 100 fathoms it would be 55 at 1,700 fathoms; and if it was 56 degrees at 100 fathoms it would be the same at the greatest depth. There was a little difference in different parts of the area, which can be explained by local causes; but, as a rule, whatever the temperature was at 100 fathoms, that it was at the bottom. Now how is it that there is this difference between the Mediterranean and the Atlantic?—in a basin of very great depth, like the Mediterranean, why should the temperature be thus curiously uniform? Why, just simply because it is entirely cut off from this general oceanic circulation, and it takes the temperature of the crust of the earth at that particular part. I will give you some curious evidence that it is the temperature of the crust of the earth. Thermometers buried deep in the soil in central Europe are found to vary very little indeed during the different seasons. Buried at about 20 or 30 feet from the surface, they are not at that depth deep enough to be influenced by what is called the "internal heat of the earth," which you experience when you go down into a deep coal-pit, for instance, or which shows itself in the hot water from very deep springs; and at that depth they are covered with a layer of earth which is a sufficiently bad conductor to prevent their being much influenced by seasonal changes; they therefore take the permanent temperature of the crust of the earth, and that

permanent temperature in central Europe is found to be about 51, 52, or 53 degrees. Now I found that there was a cave in a little island which we visited between Sicily and the coast of Africa, which has the reputation of being "icy cold." I was very anxious to visit it, but circumstances did not allow of our doing so; however, I had afterwards the opportunity of learning that the temperature of the cave is 54 degrees. Then a Maltese gentleman, the collector of customs at Valetta, a very intelligent and well-informed man, told me that it is the custom among the natives there to let down their wine to cool it in the deep tanks which they had excavated in the rock. All the rain in Malta falls during two or three months of the year, and for fresh water the inhabitants are almost entirely dependent upon that which they store up. Therefore every house has its tank excavated in the soft rock of this island; and these tanks are covered over, and very often lie under the houses, so that the sun has little action upon them. I asked him if he happened to know the temperature of these deep tanks, and he said, "Yes, it is 54 degrees." So you see we have several pieces of confirmatory evidence showing us that the bottom of the Mediterranean takes exactly the temperature of the crust of the earth at the bottom. If it were not for this movement of the water of our great oceanic basins, the bottom of the Atlantic would be 55 degrees, just the same as the Mediterranean within the Strait of Gibraltar. But see what we get a little outside that basin. On the coast of Spain, only 100 or 200 miles from Gibraltar, we found the temperature 49 degrees at 800 fathoms, and we got down to 39 degrees at 1,000 fathoms. Now this shows perfectly clearly that that low temperature could only be sustained by a constant flow of water from the Polar basin towards the southern region. Then, as I have shown you, that flow could not continue without an in-flow into the Polar basin. How could there be this constant flowing out of water from the Polar basin if it were not for an inflow to supply it? And that brings me to show you what is the force that maintains this flow. It is the continual cooling of the water as it flows into the Polar area; it becomes heavier and falls to the bottom, displacing the water previously there, pushing it on as it were. Thus, there is a constant sinking of water in the Polar area exposed to a temperature, it may be in winter, of 40 or 50 degrees below zero, or even lower; and as the water becomes colder it sinks. Every fresh layer of water that comes in from the warmer sea around is cooled; it then sinks and goes down, down, down; and this colder and denser water creeps gradually along the deepest parts of the

great Atlantic basin, and now and then, by some peculiar conformation of the bottom, it will come nearer to the surface, as it did in this Lightning Channel. If we are ever able to trace that Lightning Channel further north, it will be a most interesting point to determine what it is that sends up that cold water so much nearer the surface there, than it has been found anywhere else in the same latitude. But we have a parallel fact in the case of Gibraltar, where I have lately been able to prove very distinctly that the water from the deeper portion of the Mediterranean basin is passing as an under-current outwards through the shallowest part of the Strait, beneath the surface-current that is continually flowing inwards from the Atlantic. Thus, then, you see what is the moving force. It is this constant change of temperature which increases the density of the water and lowers its temperature too. Suppose we had a Polar column of water at this end of the room of a certain height, and an Equatorial column at the other end. As this Polar column is cooled down, it contracts and becomes denser; then the level is lowered and the water will flow towards its surface to make up that level. Very well; when this column of cold condensed water has on the top of it the additional water which has flowed in to maintain the level of that column, it becomes considerably heavier than the corresponding Equatorial column at the other end. What is the consequence? Why that a portion of the lower part of it must flow away. Thus there will be a tendency to the lowering of the level, which will draw in water from the Equatorial region; and there will always be, as that water flows in and is cooled down, a tendency to the maintenance of a greater weight of water in the Polar region; so that by these two influences—the lowering of the level, and the increase of the weight of the column—we have this constant disturbance of level and disturbance of equilibrium, producing an inflow from the Equatorial towards the Polar regions on the surface, and an outflow from the Polar towards the Equatorial area at the bottom.

This is the doctrine of the general Oceanic circulation to which I have been led. I say "I," because it has happened that I have been the member of the expedition to whose share this part of the inquiry fell, and I have applied myself to all the points bearing upon it. I have taken the opinion of some of the most eminent mathematicians and physicists of this country with regard to the validity of the principles I have advanced; and I am glad to say that I do not bring them forward merely on my own authority, but I am assured that this doctrine will stand the test of very

rigid inquiry. I was able, at a recent meeting of the Geographical Society, where I explained it, to exhibit an illustrative experiment, which was considered extremely satisfactory; and I think I can explain it to you in such a manner that you will very easily see the applicability of it, and the satisfactory nature of the result. We had a trough, with plate-glass sides, about six feet long and a foot deep, and the sides not more than one inch from each other. At one end of this trough a piece of ice was wedged in between the two sides; that represented the Polar area. At the other end we applied heat at the surface, not at the bottom,—to imitate the exact conditions of the case,—the heat being applied by a bar of metal which was laid on the surface of the water, and then carried over the end of the trough and heated by a spirit lamp; that represented the Equatorial area. Then we put in some colouring matter, red at the warm end and blue at the cold end. What happened? The water tinged with blue put in at the surface of the Polar area, being subject to a cold atmospheric temperature, immediately fell down to the bottom; it then crept slowly along the bottom of the trough, and at the warm end it gradually rose towards the surface; and, having done so, it gradually returned along the surface to the point from which it started. The red followed the same course as the blue, but started from a different point. It crept along the surface from the Equatorial to the Polar end, and there fell to the bottom, just as the blue had done, and formed another stratum, creeping along the bottom and coming again to the surface. Each colour made a distinct circulation during the half hour in which the audience had this experiment in view. Now that was a very beautiful experiment; and I can myself see no flaw in the application of the argument that what is true on a small scale in this trough is true of a mass of water extending from the Equatorial to the Polar area. I am hoping to repeat this experiment soon in a still more satisfactory way. I will tell you my idea; it is to get the largest wooden tub that I can (wood is a bad conductor), and I will call that the great ocean. Then I propose to suspend in the middle of it, which I shall call the Pole, an iron pan with a very strong freezing mixture, and then carry round the outside edge of the tub a leaden pipe on the surface through which there shall be a stream of salt water continually passing—that will represent the surface heat of the Equator. Then I intend to dispose a series of thermometers along the surface and bottom; and I am willing to stake my scientific reputation upon the fact

that we shall find the temperature along the bottom depressed down to say 35 degrees. We must try it with salt water, of course, for the reason mentioned. I have no doubt that the lower stratum will be gradually brought down to 35 degrees, representing the condition of the deep ocean bottom; and that we shall find on the other hand the surface water returning with a temperature it may be of 50 or 60 degrees from the outside of the tub towards the freezing mixture, and then that water will again carry down its cold to the bottom of the tub. I should have tried that experiment some time before, but I have been so closely engaged in the preparation of my report for the Royal Society that I have not found time yet to do so.

Now then let us consider this question of climates. You see it is a great cosmical matter, if I may use that phrase. "Cosmos" is a word which refers to the world at large. It is not a mere local phenomenon and confined to the present time, as the Gulf Stream is; but it is a phenomenon which must have had its place in all geological history. Wherever there were deep seas and Polar water and Equatorial water, there must have always been this vertical circulation. The Gulf Stream and the surface of the Arctic currents which bring back the water again, constitute the horizontal circulation. But here we have a vertical circulation. One very curious consequence of this vertical circulation, which I believe to be very important in relation to the life of the ocean, is this, that in this manner, if this doctrine be true, every drop of water in the ocean will, in its turn, be brought from the bottom and exposed to the surface. Now, in the Mediterranean there is no such circulation, and we find in the great depths of the Mediterranean an extraordinary paucity of animal life. Instead of finding the abundance of animal life which we find in the great depths of the Atlantic, we find an almost entire absence of animal life in the great depths of the Mediterranean. I will not say that is the sole cause of it, but it has a good deal to do with it. These depth are stagnant; there is nothing to change them; no periodical circulation; and, in consequence, the only vertical circulation is caused by the descent of water that has been concentrated by evaporation on the surface, and which, becoming heavier by concentration, will go down. I do not think that great depths are affected by this.

Let us now speak briefly of the nature of the Animal Life of the ocean depths. Until within a comparatively small number of years, the general doctrine has prevailed, owing especially to the predominant authority of my late most excellent friend, Professor

E. Forbes, who was at the time a most accomplished naturalist and a most profound geologist—I say, owing to the prevalence of his authority to a degree, I believe, much greater than he himself would have wished, the idea has prevailed which he based upon some researches of his many years ago in the Ægean Sea—that marine oceanic life was limited to a depth of about 300 fathoms. It was a very convenient thing for geologists, for this reason, that it seemed to account for the fact—perfectly familiar to geologists—that there are strata of very considerable depth in the present day not evidencing any metamorphosis or change of character such as would destroy fossil remains, but apparently very much in their original condition, that were almost entirely destitute of fossils. Why should this be so? Geologists were puzzled; and Professor Forbes' doctrine seemed to explain it satisfactorily—that these were deposited in a very deep ocean, and that there could be no life at the bottom where they were deposited. Now even before his death, evidence had been obtained that there was a tolerable abundance of animal life down to 400 fathoms. Dredging to that depth had been made in Sir James Ross's Antarctic expedition; and in the early period of that ill-fated Arctic expedition in which a well-known friend of mine had written home, "I have had a capital haul near the entrance of Davis's Strait at 400 fathoms"; and he gave a list of the animals obtained there. That fact, therefore, had shown that the limit assigned by Edward Forbes did not exist precisely as he had stated. Still the general idea was, "It may be 100 or 200 fathoms deeper, but there is a limit." Then the soundings taken in the North Atlantic, with reference to laying the Atlantic cable, brought up specimens of marine animals; and, in fact, previously to that small specimens, a few teaspoonfuls at a time, of the deposit forming the bed of the Atlantic, had been brought up, which, when examined with a microscope, were found to consist of minute shells, similar to those represented here, but smaller, as you will judge when I tell you that thousands of these shells would scarcely weigh a grain, little "globigerinæ," as they were called. It was found upon microscopical examination that a great part of a kind of white mud, brought up from the bottom of the Atlantic, and exceedingly similar in appearance to chalk, was composed of these little "globigerinæ." It was found also that larger animals were brought up. In the soundings which were taken between the Faroe Islands and Iceland some years ago, with the idea (after the failure of the first Atlantic cable) that a cable might be carried in separate lengths from Great Britain to North America by the various stations of Shetland to Faroe, Faroe to

Iceland, Iceland to Greenland, and so on—in the soundings then taken by Captain McClintock, Dr. Wallich having gone as a volunteer naturalist in that expedition, the sounding line brought up clustering round it a group of star fish from a depth of 1,200 fathoms. Many naturalists were indisposed to believe that star-fish had lived on the bottom at that depth; but I was myself quite satisfied with the evidence that they had so lived; for it happened that I had kept this very kind of star-fish in a vivarium for weeks together and familiarized myself with their habits, and I had never seen them swim or do anything but crawl over the bottom. There was another thing that favoured the belief that these star-fish had been found at the bottom; their stomachs were filled with globigerinæ. Further, I knew that their habit was to cluster round a rope, for I had let down a rope in the bay where I had been accustomed to dredge, and in a few hours it was covered with these and other star-fish of a similar kind. Dr. Wallich went further, and found some small crustaceans, animals of the shrimp kind, and small marine worms—tubes of marine worms, built up of globigerinæ that must have been made at the bottom. That is a drawing of it. He reasoned, therefore, that there existed at great depths not only this lowest form of life, the globigerina, but he considered that there was evidence of an abundant and varied "Fauna," which is the word we use to express the whole collection of animal life. This view was not accepted by naturalists generally. I think his conclusion was scarcely justified by the evidence. There had not been a single shell-fish brought up, no mullusk, or coral; the evidence was limited to these star fish and a few small marine worms and crustaceans. But Dr. Wallich was right in his conclusion, as the result of our own researches proved.

In our first expedition—that in which we discovered this curious contrast of temperature in the Lightning Channel—we found on a warm bottom a great abundance of animal life at from 500 to 600 fathoms, with a number of most remarkable new forms, amongst others this most beautiful sponge. This is a sponge of which the framework is composed of fibres of flint, like glass—long flexible fibres extending through the globigerina mud, some feet in length occasionally. This is a section of the sponge showing its internal structure, the large cavity of the mouth surrounded by a sort of moustache. We found four specimens of these imbedded in this chalky mud, mixed with sand, at a depth of 530 fathoms. One great point of interest in relation to this sponge is, that it closely resembles a certain group of chalk

fossils, what are known as "ventriculites," which are abundant in certain beds of chalk. Some of the most eminent of my zoological and geological friends, including Professor Huxley, instantly recognised these as the ventriculite. I do not hesitate to say it was our finding that sponge, and discovering the varying temperatures, that was the great success of our first expedition, and which procured us a very much better opportunity in the following year, when, as I have already mentioned, we were able not only to sound to the extraordinary depth of 2,435 fathoms, which is 500 fathoms lower than the depth from which the Atlantic cable was picked up, but to dredge down and take the depth and the temperature by the sounding apparatus; and from that great depth we brought up a hundred weight and a half of this globigerina mud, with a number of animals included in it, specimens of the deepest life which has been obtained from the sea bed.

Now, just to go back to cold and warm areas, because here there is a very important and curious set of facts to be named:—Working over the warm area with great care in our second expedition, and using a very valuable addition to the dredge, which the ingenuity of our captain had devised—a set of hempen tangles, like "swabs," freshly teased—these bundles of rope yarn had an extraordinary power of attracting, when drawn over the bottom of the sea, a great number of marine animals that would not so well come into the dredge; and it was curious that while they seldom picked up shells, which the dredge will pick up readily, they picked up a quantity of star fish; and in our second year they picked up two buckets full of these curious sponges, while the dredge brought up comparatively few. This proved a most valuable addition. To give you a notion of the extraordinary abundance of these things, which had previously been considered very scarce, I may mention that in one place these hempen tangles brought up at the very lowest estimate 20,000, some estimated nearly 50,000, of a small species of sea egg, which had previously been known by ones and twos, and was considered a great rarity and much prized in museums. With these hempen tangles we found a great abundance of life on this warmer portion of the area that I have been speaking of, the portion coloured red. But we found to our great surprise—for we had not the tangles the first year—that there was an almost equal abundance of life over the cold area, with a temperature at bottom of under 30 degrees,—that there was an exuberance of animal life there, with many new things. For instance, we found the whole of the bottom

covered, so that wherever we dredged we brought up pieces of it, with this most beautiful branching sponge. We found star fish in great numbers and of extraordinary variety, amongst others some most beautiful and interesting feather stars, for a specimen of one of which obtained from Iceland or Greenland I had given £5 only the year before, for microscopical examination. A great number of curious forms were there met with; but the remarkable point was this, that with the exception of a few which we found at all depths and temperatures—which seemed able, like man and the dog, to live everywhere—there was a marked difference between the Fauna of the cold area and the collection of animal life in the corresponding warm area, perhaps only 20 miles off. And the difference was still more marked in the nature of the bottom, because in the warm area the bottom was composed entirely of this globigerina mud—mud made up chiefly of these globigerinæ, either living, or their dead remains, their shells decayed and falling as it were into a powder, making a very fine mass that you would not know from a piece of chalk. I have dried some specimens of these after the salt was washed out, and no one would know them from a piece of chalk; for chalk upon microscopic examination is found to consist of exactly the same materials. We also found a sort of star-fish (Encrinite) mounted upon a long stalk. That is a drawing made from one that was brought up from a three miles' dredge. You must not suppose from the drawing that it is a large animal; the stem is about the size of a pin, and the body about the size of a pin's head; yet these animals are of intense interest to the geologist, for this reason, that in their type of structure they do not correspond with any of the animals nearest to them of the same group now living, but they correspond to one which was supposed to have become extinct with the old chalk; it is a type known as the Apiocrinite. Here is a representation of it. It is often found in the beds of clay in Bradford, Wiltshire. Dwarfed and degraded it is found in the chalk, and here we find the same thing still more dwarfed, as if, as Professor W. Thompson said, it had been "going to the bad" for millions of years.

We believe this Atlantic mud to be a continuation, so to speak, of the old chalk. I will explain what we mean by that. You know very well that a large part of England, the southern district especially, shows an enormous mass of chalk which has been lifted up from the ocean bed; and if we go across to central Europe we find large areas there of chalk on and below the surface, covered by later tertiary formations. The elevation of this chalk from the bed of the ocean marked a great period in

geology, generally known as the conclusion of the Cretaceous epoch. Now the geologist knows very well, and we may assume it as a fact, that wherever there has been a gradual upheaval of any portion of the earth's crust, there is at no great distance a gradual subsidence or lowering, so that the sea becomes dry land and the dry land sea. That was pointed out by Mr. Darwin as one result of his examination of the coral formations in the Pacific Ocean; and I believe Professor Huxley gave you some information upon this subject in a previous lecture. Now just apply that doctrine of the elevation of one part and the coincident subsidence of another to this case. There was probably a great continent in what is now the Atlantic Ocean; on the other hand there was here a sea and globigerina mud in process of formation, with an enormous number of animals embedded in it, at the time when Europe was under water at the bottom of a deep ocean. When this was being gradually lifted up, the bed of the Atlantic we may assume was going down. What would happen then? Why the animals would migrate from the one to the other area, and thus this chalk mud, the formation of which is going on at present in the bed of the Atlantic, would be continuous, these globigerinæ being the descendants of the globigerina which made the chalk of central Europe and of our own country. But then the termination of the cretaceous epoch is considered by geologists to have been marked by the disappearance of a great number of the types of life which were characteristic of that period. And if they consider that the disappearance of those types of life formed the termination of the cretaceous epoch—I do not object to the phrase, it is simply a matter of definition—what I maintain, with my friend, Professor Thompson, is, that this chalk mud which is being formed in the bed of the Atlantic at the present time, is not a mere repetition of the old chalk, but is an absolute continuation of it. We think it can be shown that the bed of the North Atlantic has never been raised more than a couple of thousand feet since that period. Now when you consider that the deepest portion is about 20,000 feet, you see that bringing it up 2,000 feet would not really alter its condition. I can state to you that many eminent geologists are quite prepared to accept that view of it, and to admit the continued existence of various types of life from the chalk down to the present time. There is really not much difference between us as to the facts, though there may be in the use of terms, depending upon the nature of the definition.

To return now to our warm and cold areas, I want to show you how remarkable a contrast there is between the life of the

one and the other. Here, for instance, at 500 or 600 fathoms we found the bottom covered with the globigerina mud, and imbedded in it a great number of animals, of which many were decidedly characteristic of a warmer climate. Going about 20 miles from that, and in some instances even less, we got into an entirely different condition—the cold area—for not a globigerina was to be seen; on the other hand we found sand, stones, gravel, and a variety of entirely different types of animal life. Now, suppose this sea bottom to be uplifted into dry land. What would be the consequence? We should have here a stratum of chalk, that is, a bed exactly like chalk in its general character, and including in it the remains of animals of a warmer climate; and actually continuous with that, on the same level, we should have a bed of sandstone including animals of a much colder climate. Now, you see what mistakes geologists would be liable to be led into, if they did not allow for phenomena of this kind.

There is one impression which I believe these researches will tend to modify, and that is as to the glacial period. It has been a prevalent opinion amongst geologists that there was at a certain period in the earth's history, geologically not very remote, an extremely cold temperature over nearly the whole earth; and that this is marked by indications of glaciers in countries where there is now no ice at all, and the finding of beds containing Arctic shells down in very low latitudes. Now with regard to glaciers on the land, I have nothing to say; these researches do not invalidate any evidence derived from them; but with regard to the deposit in the sea of organic remains characteristic of the Polar regions, you will see at once that we may have these at the present time in any part of the great Atlantic bed. We have traced Arctic shells as far south as Gibraltar, or nearly, and we have the glacial temperature there; and thus, without any difference at all in the terrestrial climate, we may have in the torrid zone the burning sun of the equator, and a few miles off we may have a glacial temperature at the bottom of the sea. Now, to a certain extent this does tend to modify geological theory, but it explains facts that were previously difficult to understand. For example, my friend, Professor Dawson, of McGill College in Montreal, wrote to me a few months since to say—"I have been excessively interested in your account of the deep-sea temperature, for I find in it an explanation of facts which I have been recently working out respecting a group of phenomena, the existence of glacial beds in a period much before what is commonly called the 'glacial period.'" He added—"I am quite

prepared to accept your conclusion that glacial beds may have been formed in any latitude and at any geological period;" and he gave an illustration of a series of glacial beds which must have been deposited in water nearly icy cold, which he had met with in a certain part of Canada. Now that is the conclusion of a very experienced and able geologist, and you see how remarkably it confirms the views that we have been led to advance.

There is just one other point that I will notice, namely, that this formation of the same kind of material very probably took place in periods long anterior to the chalk, but that it has undergone a metamorphosis into solid limestone. I have seen chalk cliffs along the coast of Antrim, in Ireland, that you might take to be a sort of white marble; they have been altered by the neighbourhood of that outburst of basaltic volcanic rock which produced the Giant's Causeway and Fingal's Cave in Staffa. There are many old calcareous rocks of very much the same character. A large part of what is known as "mountain limestone," which forms the basin of the coal measures, I believe will prove to have been formed of mud deposited in the deep sea extremely like our chalk mud at the present time, only that it has undergone a subsequent metamorphosis. We know that there are certain beds of coral limestone which were once shallow water beds, being full of shells of various kinds; but I am strongly inclined to believe that the deep-sea beds of the carboniferous limestone were formed under conditions exactly parallel to those deposited in the North Atlantic at the present time. Time does not permit me to say more with respect to the various types of life which you have before you. I have given you an idea of the curious forms (nearly all new) which we have met with, and some of which are extremely interesting from their relation to forms which are preserved to us in the chalk. As I have said, we find a considerable number of representatives of the animals of the chalk period; and yet it must be freely admitted that the Fauna, as a whole, has undergone a very considerable change, and that a great proportion of the animals characteristic of the chalk have died out; yet still we have remaining the actual creatures that made the chalk, and which are still going on making chalk.

I feel now that I have trespassed long enough on your time and attention, and I really feel that I must not add another word to what I have endeavoured to place before you, except to thank you most heartily for the kindness with which you have received me and the attention with which you have listened to me. I assure you it is a very great pleasure to address an audience so

thoroughly sympathetic and receptive, as you have shown yourselves to be.

The CHAIRMAN, in calling for hearty thanks to Dr. Carpenter for his lucid and interesting lecture, confirmed some of the statements made by the lecturer in regard to the shell and other deposits found in the bed of the Atlantic when laying the telegraphic cable.

Dr. CARPENTER, in acknowledging the vote of thanks, mentioned that the lost buoy of the Atlantic cable of 1865 was found about 10 degrees (700 miles) *south* of the spot where it had been placed, and in a direction opposite to the flow of the Gulf Stream. Dr. Carpenter accounted for this from the trailing of the long wire rope in the under current which was flowing in an opposite direction. Another fact which confirmed his theory of oceanic currents was that icebergs had been seen in the Gulf Stream, drifting in an opposite direction to that stream. This again was owing to their great depth of the iceberg in their water, which reacned the Polar under-flow.

HOW COAL AND THE STRATA IN WHICH IT IS FOUND IS FORMED.

A LECTURE

BY

A. H. GREEN, ESQ., M.A., F.G.S.,

Delivered in the Hulme Town Hall, Manchester, Feb. 15th, 1871

DR. ROSCOE, in introducing the lecturer, explained the great service rendered by the Geological Survey of Great Britain in storing up valuable records in regard to coal and other mines for the use of posterity. Mr. Green, their lecturer, was a distinguished member of this Geological Survey.

Mr. GREEN said,—ladies and gentlemen,—I am afraid that I come before you this evening with somewhat a stale subject. My friend Mr. Dawkins gave you, some time ago, a lecture on the subject of coal. In that lecture, however, he confined himself mainly to an account of the formation of coal itself, a subject quite sufficient to take up the whole of a lecture; and he did not attempt to go fully into—though he did slightly touch upon—an account of the formation of the mass of measures in which the coal beds are found. I propose to-night to attempt to supplement Mr. Dawkins's lecture by a description of the way, not in which coal itself was formed, but of the way in which the body of strata in which coal occurs have been formed. I will endeavour to give you some notion of what was the physical geography of this portion of the world during the time when coal was formed; and, lastly, show you what it is that has placed the coal in the position in which we now have to work it. I shall try to lay before you shortly an account of all that went on during the formation of the coal beds themselves, and of their associated

strata; to give you, in fact, one chapter of that far distant portion of the earth's history which the science of geology has taught us.

We know now that the earth has had a far longer lifetime than is popularly assigned to it. It used to be supposed that the earth was some six thousand and odd years old; but we know that it has had a very, very much longer lifetime; and we know that during that lifetime it has undergone a series of strange changes and revolutions. Of the earliest part of the earth's lifetime we have no actual written history left, but we are able to form, within certain limits, very reasonable conjectures of what it was like. Of times later on—but still times which, measured by human chronology, are immensely remote—we have a history; and just in the same way as the history of a nation is written upon manuscripts, or printed in books of parchment or paper, so this history of the far off portion of the earth's lifetime is written on the rocks of that thin external shell of the earth which we are able to explore by direct observation, and which, because it is so thin compared with the whole mass of the earth, is generally spoken of as its "crust." It is the province of Geology to decipher this record, but the task is by no means an easy one. It is something like working one's way through an old chronicle, the different volumes of which have been contributed at different times, by different writers of various styles and sorts of penmanship, and various powers of description. Some of the older volumes of this chronicle have so suffered from the effects of time that they are all but illegible; some of the volumes have perished altogether; the history of some periods was never written at all; and some of the volumes may be compared to those manuscripts which are called palimpsests, that is, manuscripts from which the original writing has been effaced to make room for writings of a later date. It is one of these volumes that I want to bring before you to-night, and that volume is known in geology by the name of the Carboniferous Formation; and the part of it that we shall be most especially concerned with is called the Coal Measures, being the part which contains all the workable beds of coal that occur in England.

The Coal Measures are made up of different kinds of rocks. In the main we may say that there are five different kinds of rocks in them. There are sandstones; you all know what a sandstone is. There is the rock named shale by geologists, and which is known more popularly, especially amongst miners and colliers, by the name of "bind"; there is limestone; there is coal itself;

and there is a peculiar sort of clay which is always found under each bed of coal, which is sometimes called the under-clay, and which goes by different names in different parts of the country. In Yorkshire we generally call it "spavin"; and I think in Lancashire that you know it by the name of "warrant," or "seat earth." Of these rocks the sandstones and shales have that bedded structure which shows that they have been deposited under water; that is to say, they are divided into a number of layers lying one on the top of another, somewhat in the same way that a pile of volumes lie when placed on the floor of a room. In fact, these sandstones and shales are nothing more than sand and mud that has been washed off the face of the ground by rain, carried by rain into brooks, by brooks borne on into rivers, and swept along by the rivers till they entered the comparatively still water of the sea or a large lake, and then let fall to the bottom. I shall not attempt to-night to go over the proofs of this assertion; I shall take it for granted that you are all very well acquainted with this elementary bit of geological knowledge and with the reasoning by which it is established. But though I assume the general fact that these shales and sandstones are formed in the way which I have described, it will be necessary for us to look a little more into the details of their formation.

We will begin with the shales, which are nothing in the world but hard clay, splitting up, in most cases, readily into a number of thin parallel layers. We must first of all note that the matter out of which rocks deposited under water had been formed, has been carried down in two different ways. When this matter is light or finely divided, it can be held in suspension in the water of the river which bears it along; if it is coarse or heavy, it can only be carried forward by being pushed along the bottom. The first sort of sediment makes the river muddy; the second sort, which is pushed along the bottom, causes a peculiar grating and rolling sound, which you may often notice by patiently listening as you float quietly in a boat down any large river. Shale, which we are now considering, has been formed of very finely divided mud, or of a mixture of such mud with very fine sand; and, consequently, the materials out of which it has been formed were, as a rule, carried in suspension. When the stream which carried them along entered the sea or a large lake, its velocity was checked; but this finely divided matter did not necessarily fall down plump at once to the bottom, but was carried forward very often to long distances by even the small amount of velocity which the stream was enabled to retain. And if the sea into which it was borne

was traversed by currents or was subject to tides, these currents and tides would still further aid in spreading out this finely divided sediment over larger areas. Again, if there were any interruptions in the supply of sediment, any pauses in this supply, each layer when it had fallen down would have time to harden slightly before the next layer was placed above it; and in this way the bedded structure of shale, in virtue of which it splits up into fine laminæ, has been produced. You see, then, that, on account of the very gentle regularity with which the finely divided matter out of which shale has been formed settled down, shales will show great regularity of thickness over a large area, and will extend to very great distances, far away from the mouth of the river which brings down this matter; and, upon the whole, the general character of shales will be uniformity of composition and regularity of bedding over very, very large areas. In this diagram (section of coal measures) you see that the beds of shale present throughout a uniformity of thickness and bedding. That is the notable feature about the shales.

We next come to the sandstones, which are formed of a mass of sand, or, as it would be called in mineralogical language, "quartz;" and because sand or quartz is a very hard substance, it is not easily ground down to a finely divided state, and, therefore, its grains are large; also quartz is a heavy substance. For these two reasons, the materials out of which sandstone are formed cannot be carried in suspension; but, as a rule, except the current be very violent, the only way in which it can be borne down in ordinary currents is by being pushed along the bottom. When a running stream that is pushing forward this sandy matter enters still, deep water, its velocity is checked, and the sand, instead of being carried out to very great distances far and wide, like the finely divided silt out of which the shale was formed, sinks rapidly to the bottom and accumulates in a bank of a wedge shape, which forms near the mouth of the river that has brought down the matter. [The lecturer illustrated this by making a sketch with chalk upon the blackboard.] For instance, this represents the surface of the land, and that the water, and we will suppose a river entering and rolling down a quantity of this coarse sandy matter; this cannot be carried very far, but will be thrown down in a bank. In the shallow water over the top of this bank, the stream will still retain its velocity, and, therefore, it will keep rolling sand along; but, on reaching the deep water, the sand will be again thrown down and another bank will be piled up; and so on, bank after bank will be piled up of sandy matter,

all of the same shape; so that, in the end, these beds of sandstone will be always wedge-shaped, with their thick end towards the source from which the sediment comes, and their thin end pointing in the opposite direction. In this diagram the yellow parts represent the bands of sandstone, and you see that in every case they are just such wedge-shaped masses as I have described to you. They are found to be such in all actual cases, and in many cases, if I were sinking a coal pit,—here for instance—I should pass through three thick beds of sandstone. I might possibly in sinking here miss the two upper beds of sandstone, and only find the lower one. Sometimes in a railway cutting you will see the actual wedging out of these beds of sandstone and their dovetailing into the shales exactly in the way shown in that diagram. I may explain a little further the way in which that dovetailing has been produced. The stream which brought down the sandy sediment out of which this bed of sandstone was formed, carried down also at the same time a quantity of finely divided mud or silt. The sand was thrown near the mouth of the river; the silt, on account of its finely divided state, was carried further out to sea, and, therefore, while a little bank of sand was formed near the mouth of the river, a bed of shale was deposited somewhere out at sea. Again, more sand was rolled over the top here, adding to this sand bank, and the finely divided silt was carried out and deposited as shale there. So that we get constantly in that way formations of sandstone near the shore, and of shale far off the shore, going on simultaneously.

There is one more point to notice about the formation of these sandstones. [Illustrated with blackboard.] Supposing that we have here one of these banks of sand which is being formed in the way I have described. This being the surface of the water, the sand is rolled along here by the force of the current, and when it arrives here the current loses its carrying force and the sand is thrown down, and it will roll over and be arranged in a little sloping layer. More sand will be carried on, and another layer with a similar slope will be added, and so on; so that in the end, these sand banks, besides showing great main lines of bedding, such as these and these, will also be traversed by a number of planes of bedding running across diagonal wise, and inclined at an angle to the main lines of bedding. Note here specially that these lines of cross bedding all slope in the direction in which the current is running. Therefore, if I see a sandstone like this, in which all the planes of cross bedding dip in a certain direction, I know that it was produced by a current which ran in the same direction as

the planes of cross bedding dip. The same conclusion will be derived from the fact that the sandstone bed is thickest towards the rise and thinnest towards the dip of the planes of cross bedding; the two facts both point to the same conclusion.

We next come to limestone. Limestone was not formed out of sediment carried down by rivers into seas or lakes, but all great masses of limestone have been formed in this way. Limestone is mainly made up of carbonate of lime, and sea water contains a small quantity of carbonate of lime in solution. Now, there are certain animals that live in sea water, shell fish, corals, &c., which have the power of extracting this carbonate of lime from the sea water, and out of it building up the hard dwellings in which they live, or some part of their animal organism. On the death of these animals, their hard parts, which are formed of pure carbonate of lime, fall to the bottom of the sea, and there accumulate in a great heap, and this great heap, by pressure and chemical changes and other agencies, is afterwards turned into limestone. These animals that secrete the carbonate of lime from the sea water, as a rule, flourish only where the water is clear; they cannot live in muddy water; and therefore they are found, as a rule, in water so far distant from the shore that no sediment borne by rivers can reach them. From this fact we draw a very important conclusion, which we shall find very useful further on in the lecture; and the conclusion is this—that wherever we find a great mass of nearly pure limestone, then we are quite sure that at the time the limestone was formed the spot where it is now found was far out at sea; but wherever we find the limestone becoming earthy, and intermingled with sedimentary deposits, such as sandstone and shales, we know then that we are getting near the old coast line.

The next class of rocks are the clays that are found beneath every bed of coal, and which are known as under-clays, or warrant, or spavins. They vary very much in mineral composition. Sometimes they are soft unctuous clay; sometimes clay mixed with a certain proportion of sand; and sometimes they contain such a large proportion of silicious matters that they become hard flinty rock, which many of you know under the name of "gannister." But all underclays agree in two points. They are all unstratified; they differ totally from the shales and sandstones in this respect; and instead of splitting up readily into thin laminæ, they break up in irregular shaped lumpy masses. And they all contain a very peculiar vegetable fossil called "stigmaria." In this diagram there is represented a bed of underclay with the

coal above it containing a number of these stigmaria, which you see are branched vegetable fossils, dotted all over with little pits, and from these run out in every direction into the clay innumerable black filaments, sometimes to such a great extent that the whole clay is one thickly matted mass of them. A good many of them are shown in this diagram, but not unfrequently you will find the under-clay much more thickly penetrated by these black threads of the stigmaria. When we get the stigmaria very perfect, it is found to have a shape something like this—in the centre there is a flat disc, and from that disc there are spread out generally four arms, which at a certain distance from the disc bifurcate, or divide into two, and each of these branches again divide into two, and from these branches the thin filaments are given off in great numbers. This strange fossil was for a long time a sore puzzle to fossil botanists. Brogniart suggested a long time ago, on botanical grounds, that it was very likely a root. Sir Wm. Logan pointed out the important fact that it was always found in under-clays; and that when it was found, as it is sometimes, in other beds, in shales or sandstones, it always then presented the appearance of having been more or less rolled, and that it had not got these long filaments attached to it; in fact, that when you see it in under-clay it looked perfectly well at home, but if you saw it anywhere else it looked by no means so comfortable and at its ease And, last of all, Mr. Binney fairly solved the problem by the discovery of a tree embedded in the coal measures, and standing erect just as it grew, with its roots spread out into the stratum on which it stood. These roots were stigmaria, and the stuff into which they penetrated was an under-clay. Professor Roscoe kindly reminds me that the casts of these actual fossils may now be seen in the Museum in Peter Street, and splendid fossils they are. The general appearance of this fossil is shown here. There is the tree standing erect as it grew, and from it are the roots spreading out into the bed on which the tree stood. These roots were found to be stigmaria; this is the under-clay, with a thin bed of coal lying on the top of it. There can be no doubt whatever now as to what the true explanation was. The stigmaria were roots of trees like this, or some other trees, and the under-clays were the old soils on which these trees grew. It is not very often that we still find the trees standing erect, because certain circumstances, which we shall come to by-and-bye, have generally thrown them down; but even when we do not find these trees standing erect, we often find them in very large numbers in the roof of the coal, evidently having been tossed over, and lying there flat and squeezed thin by the pressure of the measures that lie above them.

Lastly we come to coal itself. I need not say much, after the full explanation that Mr. Dawkins gave to you, about the vegetable origin of coal. It is a thing universally admitted on all hands, and he explained it so fully, and dwelt so thoroughly on all its details, that I shall take it for granted you are all perfectly convinced that coal has been nothing in the world but a great mass of vegetable matter. The only question is—How were these huge masses of vegetable matter brought together? and you must realise that they were very large masses indeed. Just to take one instance. The Yorkshire and Derbyshire coal field is somewhere about 700 to 800 square miles in area, and the Lancashire coal field about 200. Well, in both these coal fields you have a great number of beds of coal that spread over the whole of them with tolerable regularity and thickness, and very often with scarcely any break whatever. And this, as we shall see by and by, is only a very small portion of what must have been the original sheet of coal; so that you see we have to account for a mass of vegetable matter perfectly free, or nearly free from any admixture of sand, mud, or dirt, and laid down with tolerably uniform thickness over many hundred square miles. At one time it was supposed that the coal was formed out of dead trees and plants, which were swept down by rivers into the sea, just in the same way as shales and sandstones were formed out of mud and sand so swept down. It is not very easy to see how in this way such a light matter as dead wood could be spread with this wonderful regularity and uniformity over such very large areas. The fatal objection to this theory, however, is, that rivers would not bring down dead wood alone, but they would bring down besides sand, mud, and other matters, and that in the bottom of the sea the dead wood would be mixed with these matters, and instead of getting a perfectly unmixed, or very nearly unmixed, mass of vegetable matter, we should have a mixture of dead plants, sand, mud, and other things, which would give rise certainly to something like coal, but to something very different, as any one who tries to burn such coal will soon find out, from a really good, pure house coal. So that this theory, which is generally known as the "drift" theory, was totally inadequate to account for the facts as we know them. The other theory was that the coal was formed out of plants and trees that grew on the spot where we now find the coal itself. On this supposition we could very readily account for the absence of any foreign admixtures of sand, mud, or clay in the coal; and we could also understand, very much better than by the aid of the drift

theory, how the coal had accumulated with such wonderful regularity and uniformity of thickness over such very large areas. This theory was for some time but poorly received; but after the discovery of Sir William Logan that every bed of coal had a bed of under-clay beneath, and the discovery of Mr. Binney, that these under-clays were true soils on which plants had undoubtedly grown, there was no doubt whatever that this was the real and true explanation of the matter. I dare say that many of you have had occasion to walk across peat bogs, for there are many of them to be found within a few miles of Man chester; and it is not at all a hard thing to see within a few hours of one another a section of coal and its underclay, and a section of peat bog made by one of those deep gullies which you find in all large peat bogs, and the resemblance between the two is very striking indeed. The peat bog is a great mass of vegetable matter, which is every year growing thicker and thicker; and underneath it there is almost always a bed of thin clay, in look very much like the under-clays; and this thin clay is penetrated by the rootlets of the moss forming the peat, exactly in the same way as the under-clays of the coal measures are penetrated by the stigmaria and its rootlets. But you must not suppose that the plants out of which coal were formed were exactly the same as the low type of moss which form our present peat bogs. Mr. Dawkins told you, I think, quite as much as is known about these coal plants. A good deal has been learned lately about them, and still there are many points with regard to their affinities to modern vegetation which still want to be made out. However, it is pretty certain that they were for the most part of a loose, succulent texture, and that they grew very rapidly indeed.

You will have noticed that there is one step more wanted to make complete this theory of the growth of coal on the spot where we now find it. The coal is found, as this diagram shows, inter-bedded with shales and sandstones. These shales and sandstones we have seen were formed beneath the water of the sea, and as long as they remained there, of course no plants could grow upon them. The question is—how was a land surface formed for the growth of plants? It must have been formed in some way or other by the sea bottom having been raised above the level of the water. Now we have distinct proof in very many cases that elevation of the sea bottom and depression of the land is now going on in many parts of the earth's surface. And, therefore, we shall be assuming nothing beyond the range of our experience if we say that such elevations and depressions went on during

coal measure times. The coal measure times must have been times during which the same spot was now below the sea and now dry land over and over again. There was a land surface on which plants sprung up and grew fast and multiplied rapidly, and as they died, fell and accumulated in a great heap of dead vegetable matter. After a time this layer—for "layer" would be a better word than "heap"—of vegetable matter was slowly and gently let down beneath the waters of the sea,—so slowly and gently that the water flowing over it did not, as a rule, disturb the loose pasty mass. And then by the method I have described to you, shales and sandstones were deposited on the top of this mass of dead vegetable matter. By their weight they compressed it, and by certain chemical changes, which I shall not have time to go into, even if they were satisfactorily understood, this mass of vegetable matter was converted into coal. After a time the shales and sandstones which had been piled up above this stuff which was to form coal for the future, were again elevated to form a land surface; upon this another forest sprung up, and by its decay produced another mass of vegetable matter fit to form coal. This again was let down below the water, more shales and sandstones were deposited on the top, and this process went on over and over again till the whole mass of our present coal measures was formed.

You will now see how it is that we so seldom find trees standing upright in the way represented in that diagram. As the land went down, they would in very many cases be toppled over by the water as it flowed against them; or their base would be rotted by the water, and they would fall over or be blown over. That is the reason why, in most cases, we do not find the trees standing upright, but find them toppled over and lying flat on the roof of the coal bed. But in a few cases, when the depression was very gentle and gradual, the trees were not overthrown, and the shales and sandstones accumulated around them and preserved them in the position in which they grew.

Having now explained the way in which each of the several members of the coal measures have been formed, we will see how they are put together when we look at the coal measures as a group. This is what is called a geological section. Supposing you were to dig a trench some hundred yards deep and a good many miles long across this great coal field, you would see something like this, in the sides of the trench, where the dark black represents the beds of coal, the lighter black the shales, and the yellows the sandstones. We shall come to the details of this by-and-bye; for the present I want you particularly

to note what I have already impressed upon you—the wedge-shaped form of the sandstones, and the direction of their planes of current bedding; these show that they were formed, not by one single river, but by many rivers entering the sea at different points and flowing in different directions. This sandstone, for instance, must have been formed by a river flowing in that direction, and that little wedge-shaped bit at the top by one flowing in the opposite direction; that by a river flowing to the right, and this by a river flowing to the left. If instead of a section I had taken a map and determined by means of these planes of bedding the direction of the current of the different rivers that must have contributed their share to the coal measures, you would have had rivers falling in in every direction.

I think we shall now be able to form some opinion as to what sort of sea it was in which these coal measures were deposited. What I said just now shows that they were not the work of a single river; they are not like the Deltas of the great Mississipi, or the Ganges, which are formed in the main by a single river, but are due to a large number of rivers flowing from different quarters in different directions. Again, in these beds we find constantly the remains of land plants—plants that grew on land. These plants have evidently been drifted, because they are seldom or never quite entire. But it is evident they have not been drifted very far, because though leaflets have been broken from branches, and branches from trees, the broken portions are themselves singularly perfect; in fact, in some cases the ferns are so beautifully perfect that they might have been preserved by design by a botanist. Therefore these plants, which grew on land, have been drifted, but they have not been drifted very far; that is to say, the sea in which these measures were deposited always had land at no very great distance from it. These two facts—the fact that the deposits must have come from different quarters, and that the land could never have been very far off—will be explained if we suppose that the coal measures were deposited in a land-locked sea, fed by rivers flowing into it from different quarters. And again, because a large number of the coal measure rocks are formed of such heavy materials that they could only have been carried down by being pushed along the bottom, and because currents sufficiently powerful to push them along the bottom could not exist in deep water, we know that the sea must have been tolerably shallow throughout. Therefore you arrive at the fact that the sea in which these coal measures were deposited must have been land-locked, and in no part of it very deep.

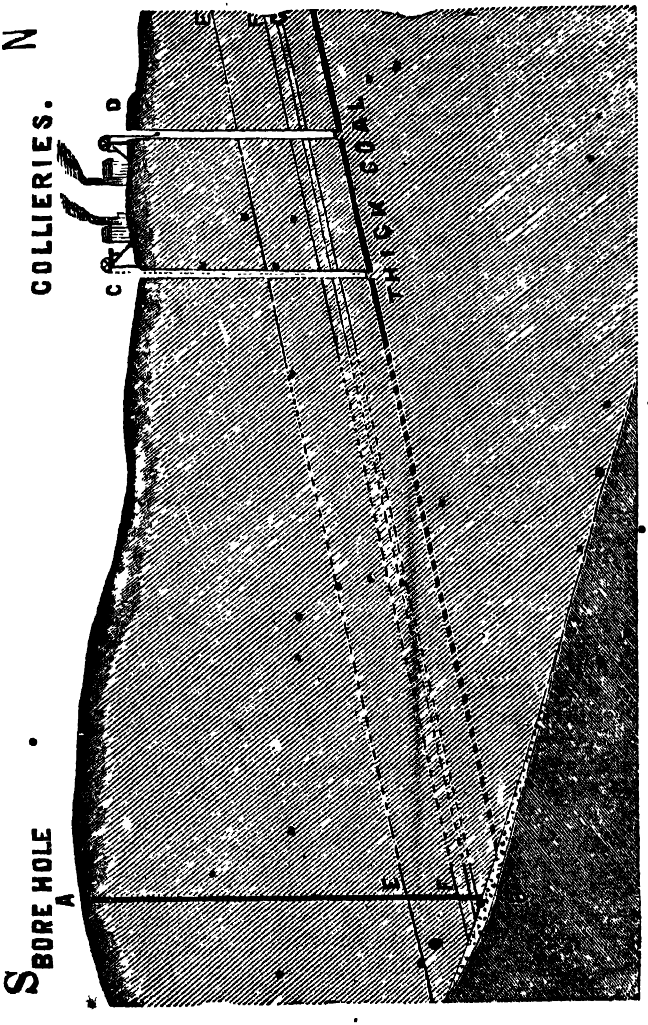
However, a difficulty occurs here. The coal measures are of enormous thickness—10,000 to 12,000 feet thick in some cases—and therefore you might suppose that they must have required a sea of at least this depth to allow room for them to accumulate in. This difficulty is very easily got over. Suppose that the sea was shallow, but that during the whole time of the formation of the coal measures its bottom was sinking very slowly, but regularly; if the rate at which the bottom sank, and therefore the rate at which the sinking tended to deepen the sea was about equal to the rate at which the deposition of the sediment tended to fill it up, the sea would remain shallow throughout, and still we may have any thickness of beds deposited in it. However, though I have spoken of this sinking going on regularly, which it did for the most part, there were exceptions. You have seen that it was necessary for the formation of coal beds that we should have a land surface for the trees to grow upon. Now, how was this land surface produced? It must have been produced undoubtedly by pauses which occurred every now and then in the sinking of the sea-bottom. When the sea-bottom ceased to sink, the deposition of sediment would tend to fill the sea up. Whether this alone would suffice to produce the land surface appears to me a very open question. I cannot conceive a deposition of sediment entirely filling up the sea; it might shallow it to a great extent, but I cannot conceive that it would entirely fill it up; therefore I think it likely that every now and then a pause occurred in the sinking, and that in consequence of this pause, the deposition of sediment tended to fill the sea up, and did fill it up to a certain extent, and that then the work was completed by a slight upheaval of the sea-bottom. Possibly it all might have been done by upheaval; but in any case I think there might have been some little upheaval, though deposition of sediment may have contributed its share in producing this land surface. And when the land surface was formed, trees began to grow upon it in the manner I have already described.

I think we shall understand the case better if I lay before you an actual instance; and therefore I will explain to you, as far as I can, what was the position and where the shores were of the sea in which the coal measures of the centre and north of England were deposited. This map, ("showing the general distribution of land and sea during the carboniferous times") represents the probable distribution of land and sea during the time when our coal measures were formed. The brown represents the land, the blue the sea, and the dark black the present distribution of land.


MAP SHEWING THE GENERAL DISTRIBUTION OF LAND & SEA DURING CARBONIFEROUS TIMES
SCOTLAND
ENGLAND
LAND
SEA

We have over the centre and north of England a number of detached patches of coal measures, known as coal fields. There are the little coal fields of Leicestershire, Warwickshire, South Staffordshire, Coal Brook Dale, North Wales and Anglesea; then there are the great coal fields of Lancashire, Yorkshire, Derbyshire, and Northumberland, and a little coal field near Whitehaven. There are also coal fields in Scotland, and there are large patches of coal measures, though not containing much coal, in Ireland. Now there is very little doubt whatever that all these patches of coal measures in the north and centre of England, and very likely the coal measures of Scotland and Ireland, are only parts of one great sheet of coal measures which stretched at one time not only over the spots where we now find coal-bearing rocks, but also over all the intermediate area. Probably all these detached patches were united in one great sheet of coal measures, and we have to determine the boundaries of the sea in which this sheet of coal measures was formed. Of course it takes in all existing coal fields; and the only question is—How much further did it extend? Now, properly to solve this question, I shall have to take you a little further down among the measures, and instead of dealing with the coal measures proper, to bring before you the whole of the carboniferous formation. The carboniferous formation consists of two parts—the upper part, of which these coal measures may be taken as the type, consisting of shales, sandstone, and clay; and the lower part, which consists mainly of limestone, this limestone being in some cases of great thickness, and free from any admixture of foreign matter; and in other places being inter-bedded with sedimentary deposits of shale and sandstone. Now you will recollect I said a little time back that limestone was formed by the agency of animals which secreted carbonate of lime from the water, and that wherever we found this limestone pure and thick, the water must have been deep and clear and far away from the shore, but that wherever this limestone is mixed up with sedimentary deposits, we know we must be near the old coast line; and it is by the consideration of this fact that we are enabled mainly to determine the boundaries of the old carboniferous sea. In the centre of Derbyshire, as shown in this section—where blue represents the limestone, and dark brown represents the rocks that form the bed of the old carboniferous sea—we have the limestone quite pure and of very great thickness; but as we go southwards into Leicestershire we find the limestone becoming thinner and thinner, and mixed up to a great extent with beds of shale and sandstone.

as shown by those yellow wedges. We know, then, that in the coal measure times there was deep sea in Derbyshire, and that in Leicestershire we were very near the old coast line. If we go still further south, into South Staffordshire, we find the limestone wanting altogether; and therefore we know that we must be there still closer to the old coast line than in Leicestershire. The Leicestershire coal field is that tiny patch, and as I said we are there near the old coast line, I have therefore run the coast line up into a little promontory towards the Leicestershire coal field. The South Staffordshire coal field is shown by this patch, and as there also we are near the old coast line, I have run up the land into a similar promontory there. In this South Staffordshire coal field they found some time ago a very singular trace of this coast line, which this diagram is drawn to explain. The coal which is of most importance there is known as the "thick" or "ten yard coal," and over part of the field it had been very largely worked. In sinking to this thick coal they passed through a series of easily recognisable measures. Of these measures I have only put four well known coals. You will see that we have here three of these coals close together, then a long interval without coal, and then another coal; and in all former sinkings the thick coal had been found at a certain depth below this easily recognised group of beds. They then, some way south of any collieries, put down a bore hole in search of coal. They found these overlying measures as usual, and according to all past experience they were justified in expecting that at the usual distance between these upper coals they would come to the thick coal. But to their great disappointment, shortly after passing through this group of beds, they came, not to the thick coal as they expected, but to a mass of stuff that looked like gravel formed out of rocks known to be much older than the coal measures. The explanation was perfectly easy; they had got upon the old shore line of the carboniferous sea, and this mass of pebbles was nothing in the world but shingle that had been formed on that ancient shore, just in the same way as we see shingle forming every day now by the waves on a modern beach. You see clearly now why that bore-hole did not reach the thick coal. The slope of the land being to the north, the highest beds of coal stretched further to the south than the lower beds, therefore they found the higher beds, but the thick coal had been cut off when it reached that old coast line.


S
BORE HOLE
A
COLLIERIES.
N
C
D
THICK COAL
E
F

It is by considerations like this that the boundary of the carboniferous sea has been laid down. We have not time to go into details, but I may just mention one reason why I have put so much land in this quarter up towards Norway. A great many coal measure sandstones had evidently been formed by the disintegration of granite; and Mr. Sorby pointed out that granites having exactly the nature required to furnish these sandstones are found in great quantities in Norway and Sweden. Also, when we observe the direction of the plains of current bedding in the carboniferous sandstones, we find that in a very large number of cases they slope toward the south-west, and therefore that the current which brought their sand must have come from the north-east. For these reasons—because Norway and Sweden lie in the quarter indicated by these planes of current bedding as the source of the sand, and also because the rocks there are just such as would furnish the materials of many of the carboniferous sandstones, we conclude that a large portion of the coal measures was probably derived from the waste of land formed by a southward prolongation of the great Scandinavian peninsula. There is one more fact which I think worth notice, which tends to confirm the distribution of land and sea, as shown on that map. You will see that I have drawn a narrow tongue of land running across the centre of England, and introduced sea again to the south of it. There are reasons for that which I cannot go into now. This section, which has reference, not to the coal measures, but to the limestone part of the carboniferous formation, runs from Leicestershire up into Scotland. You will note that at the southern boundary of the limestone, though there are inter-bedded masses of sedimentary rocks, they do not run very far into the limestone. But here on the north you get long tongues of sandstone and shale stretching far away south. Now, the reason of that is, the sediment which formed these small tongues on the south was brought down by rivers traversing only this narrow tongue of land; and that tongue of land being very narrow, only gave rise to small rivers which would not be able to carry down very much sediment, and which, because their velocity would be small, would be unable to carry that little very far into the sea; hence these wedges of interstratified shales and sandstone on the south do not reach very far; but on the north the rivers would drain a very large area of probably mountainous country; they, therefore, would be large rivers, bringing down very large masses of matter, and on account of their velocity would be able to carry that sedimentary matter very far out to sea. Hence we have these long tongues on the north running to a great distance out among the limestone.

We will now sum up the succession of events that went on during the time when the carboniferous rocks were being formed. Over an area occupied by Scandinavia and the north of England, Ireland, and Scotland, there was the distribution of land and sea shown on that map. At first, in the centre of this land-locked marine area, the water was deep, and though streams charged with sediment no doubt flowed into it, they would on entering this deep water have their velocity checked, and would very soon after leaving the land part with their sediment. Therefore the water in the middle would be clear and free from mud, and this clear water would be a fitting home for those lime-producing marine animals which form the limestone in the way I have described. Therefore there was formed there a great thick mass of pure limestone. But round the coast matters would be very different. The water there would be more or less muddy, and the limestone-creating animals would have by no means so easy a time of it. Perhaps the water would be clear for a time, and they would be able to live and build up a layer of limestone. Then there would be an irruption of mud or sand which would either kill them or drive them away, and form a layer of shale or sandstone. Then, again, there might be clear water for a time, and the limestone-forming animals would come back and form another layer, producing this interbedding of shale with limestone shown in that section. But after a time a change came over this carboniferous sea. The sea bottom was gradually upheaved over the deep central space, and the water became shallow throughout. The rivers now, when they entered this water, instead of having their velocity suddenly checked, would be able to keep up their currents and their carrying power over nearly the whole of the marine area, and in every direction it would be traversed by streams of water bringing in large quantities mud, sand, and other such matters. Water fouled in this way would no longer serve as a dwelling place for the limestone-producing animals, and they would be either killed off, or they would have to migrate to some more favourable haunts. When this state of things had been brought about, that is to say, when the sea was made shallow throughout, there set in a very gradual and regular sinking of the sea bottom, so that as fast as the deposition of sediment tended to fill up the sea, the sinking of the sea bottom tended to deepen it, and the two processes went on at the same rate; sediment, therefore, was constantly deposited in the sea, which at the same time remained permanently shallow throughout. In this way shales and sandstones were formed. But every now

and then a pause would occur in this sinking, and during this pause, the deposition of sediment would rapidly fill up the shallow sea; and when it had very nearly filled it up, perhaps a slight elevation of the sea bottom would take place, and the whole or part of the area would be converted into dry land; and whenever this took place a luxuriant growth of dense vegetation sprang up upon this dry land, and as it grew and flourished and the trees died and fell to the ground, there accumulated a great layer of dead vegetable matter. There would be very little admixture of sand or mud with this vegetable matter, because the streams that did find their way over the nearly flat surface would be sluggish and unable to bring much with them, and what little mud they did bring would be filtered out of them as they trickled through the dense mass of underwood that grew all around this forest. This is clearly illustrated by Sir Charles Lyell by the case of the cypress swamps of the Mississippi, where he noticed that though the water all around was largely charged with sediment, but that after having trickled through the undergrowth that surrounded the trees on all sides, it issued quite pure. If the plants actually grew on land, which they most likely did, this land was probably only just raised above the sea level. Every now and then a slight sinking would occur, which would bring the mass of vegetable matter just below the surface of the water. Then into this water mud or sand would be poured and form a thin layer of shale and sandstone. Then, if as light upheaval occurred, fresh vegetable growth would take place on the top, and another bed of coal would be formed; and then, if this sunk again, there might be another thin layer of shale and sandstone formed, and above that another mass of vegetable matter. So that in this way, what are called, in mining terms, "partings" between the beds of coal were brought about. The most striking instance of this is in the ten-yard coal of South Staffordshire, which is made up of many beds of coal, twelve or thirteen in number, which in one portion of the field all run together, making one great mass of coal ten yards thick. As you trace these beds northwards, they are gradually separated by wedge shaped masses of shale and sandstone coming in between them. That was brought about in the way I have described.

Again, sometimes during the formation of beds of coal, a large river would by some change of physical geography be turned upon a bed of vegetable matter and eat out in it a great valley, such as we have shown here. You have here a thick bed of coal gradually wedging out to nothing. In this case there is no doubt that it was originally a bed of coal of uniform thickness stretching over the

whole area, and that a river was turned across the sheet of vegetable matter and cut out in it a hollow, and afterwards sand filled up the hollow, and the place of the coal was taken by sandstone. These things are of constant occurrence, and are known as "rock faults."

I do not know that we can point to anything now-a-days that exactly resembles the state of things that must have gone on during the time these coal measures were formed; but there are a great many cases which are strikingly analogous to them. I shall not attempt to describe them to you, but may just mention the mangrove swamps that very often fringe the coasts in the tropics, and the cypress swamps of the Mississippi, which Sir Charles Lyell has described so well; and also the great dismal swamp of Virginia, which appears to me to furnish the nearest analogue to the state of things that existed during coal measure times. This is well described in Sir Charles Lyell's second visit to the United States. And I recollect reading an admirable description of it in Dr. Russell's (*Times* correspondent) account of his travels in the Southern States of America during the war. Dr. Russell did not pretend to be a geologist, but he described what he saw, and his account is a very valuable contribution to geological knowledge. There is no earthly reason why any working man—and I believe I am addressing mainly working men to-night—who has his eyes and wits about him, should not, by noting and describing what he sees, as Dr. Russell did in this case, add to our stock of geological knowledge.

I have just one more point and then I have done. You will very naturally ask me, if these coal measures once stretched over all this area coloured blue on the map, how is it that we have been so unlucky as to have so little of it left? The reasons are very simple. Originally these beds of coal, shales, and sandstones lay stretched out in level planes, as shown in that section; but after a time, the slow subsidence of the sea bottom, which had gone on continually during their formation, ceased, and a great upheaval took place. And not only were the beds upheaved, but during their upheaval, they were thrown into hollows and bent into arches; so that instead of lying flat, they came to take such shapes as this. [Here the lecturer drew a sketch on the black board]. Now, as long as the beds lay flat at the bottom of the sea they were safe enough, because through the deep water no powerful currents could run to wear or denude them away; but directly they begin to be moved up into these folds and arches, the crests of the arches would be brought up nearly to the

sea level, and they would then come within the destructive action of the sea waves, and the sea pared them off, slice after slice. You must not suppose that the folding was produced all at once by any violent movement. The folding and upheaval probably went on very slowly and gradually, and as bit after bit of each of these crests or arches was brought up to the sea level, it was pared off in the manner I have shown. Further upheaval would bring still more within reach of the action of the waves, and still more would be pared off; and so it would go on paring and paring off, until at last we should only have left the parts which occupied the depressions or troughs, and the portions bent up into these arches would be totally swept away. That is the reason why we have such a small portion of the original sheet of the coal measures left, and also why the portions we have lie, almost invariably, in troughs or basins. If you ask me what it was which brought this upheaving and folding of the beds, I can only answer that this is one of the great problems of geology which still wants solution. Several plausible explanations have been offered, but as yet we know nothing for certain about the cause of such movements.

I have tried your patience long enough; and I have to thank you for listening to me so attentively; but I have by no means exhausted the subject. All I have had time to do has been to sketch out the outline, and I must leave you to fill up the details for yourselves. However, I shall have done all I could reasonably expect, if for the future a sandstone quarry or a block of coal becomes more full of meaning to any of you than it was before, and if I shall have aroused in you an interest in one of the many curious stories which natural objects have to tell us if we only learn how to question them aright.

On the motion of Alderman RUMNEY, the thanks of the audience were given to Mr. Green for his very interesting and instructive lecture.

THE SUN.

A LECTURE

BY

J. NORMAN LOCKYER, ESQ., F.R.S.,

Delivered in the Hulme Town Hall, Manchester, February 25, 1871.

Dr. ROSCOE, in introducing Mr. Lockyer, said there was no man living who knew more about the physical constitution of the sun than their distinguished lecturer, to whom he felt much indebted for taking the trouble to make a special journey from London to deliver this lecture. Dr. Roscoe also expressed his indebtedness to Mr. Harrison for placing the whole of his apparatus at their disposal, and superintending its use himself.

Mr. LOCKYER said :—It is a great satisfaction to me to know that in coming before you to-night to say a few words (for, after all, in an hour or so one can only say a few words) about the sun, my way has been made smooth for me by that altogether admirable discourse which has recently been delivered to you by Professor Roscoe. He told you how Newton arranging the facts which he had inherited from those who had gone before him, touching the action of a little piece of glass called a "prism," discovered that white light, including the light which we get from the sun, consists of different colours ; and Professor Roscoe also told you how Wollaston, Fraunhofer, and especially Kirchhoff and Bunsen, took up the wondrous tale, until, at last, nearly the whole story which is to be read, by those who are cunning enough to read it, in that glorious cypher-band which is called the solar spectrum, was placed before man's view, and the secret of the sun, to a very large extent, might be said to have been revealed. This, then, is my starting point to-night. I take it for granted, not only that all of you who were privileged to hear it have recollected that important

lecture, but also that the size of the sun, its distance from us, and how the planet on which we dwell is but a little atom, so to speak, travelling diligently round that sun, year after year—I say I take it for granted that what we may call the "Sun's place in Nature" and the most important solar discoveries of Kirchhoff and Bunsen are, to a certain extent, familiar to you.

Now, you will have understood, from what has already been placed before you, that the work which was done by Kirchhoff dealt with the sun, to a very large extent, as if it were a star. It is quite true that the sun is a star; but it is the nearest star; and it is on this account that we have been enabled recently to make some advances, probably of some importance to science. You know that the stars are so very far away from us that, even with the largest telescopes which we can command, we can never get anything more out of them than a small point, the brilliancy of that point in the telescope depending upon the size of the telescope; we can never make a star look as large as the sun; nor can we make it look as large as even the smallest of our fellow planets. But with the sun you all know the case is different. Not only is the sun obviously very much larger than a star appears to be because it is so much nearer to us, but it is so large that sometimes wonderful things called "spots," are even visible on the sun to the naked eye. Now, the use of even a small telescope enables us to observe the different parts of the sun's face, and so you see we are in a position to learn very much more about the sun than we can about the stars. I should like, before I go further, therefore, to give you, as it were, a general view of the sun, and explain some of those phenomena which have been long known to those interested in the subject. Now here, on this screen, we have a small portion of the sun represented. It is not the whole of the sun, as you see, but it includes a part very near the sun's edge, or as astronomers prefer to call it, the sun's "limb;" and you see that on the general surface, which is represented by the brighter portion of the diagram, there are here and there darker portions, these are the "spots." There is one very obvious spot there, and another there; and there is another one here, nearer the sun's edge.

Now I hope I shall have time to explain a few hard words I shall have to use as I go on; so that I may as well tell you at once that the brighter portion of the sun which you see here is called the "photosphere"; that is to say, the "light sphere"; because most of the light which we get from the sun comes from that portion. The meaning of the term "sun spot" speaks for

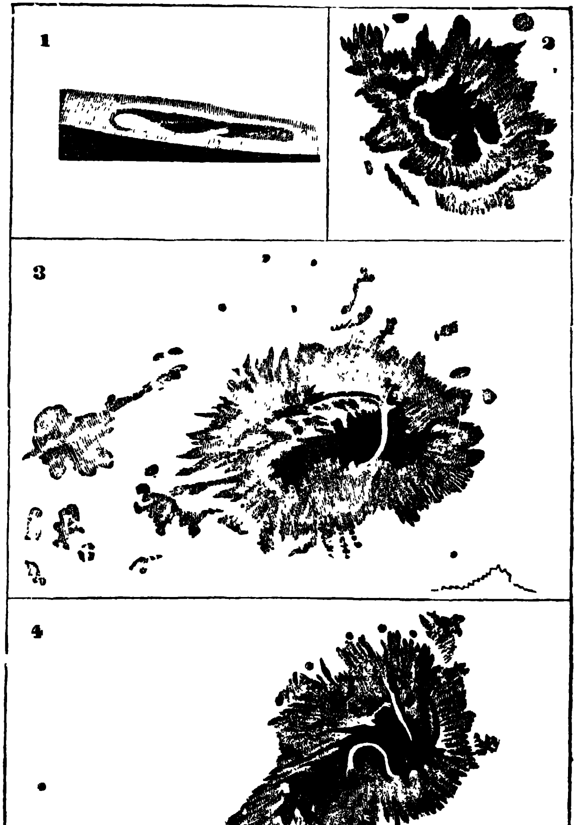


Fig. I.—Sun Spots. The Great Sun Spots of 1865.
1.—The Spot entering on the visible disc, October 7th. 2.—October 10th.
3.—October 14th, showing the formation of a bridge. 4.—October 16th.

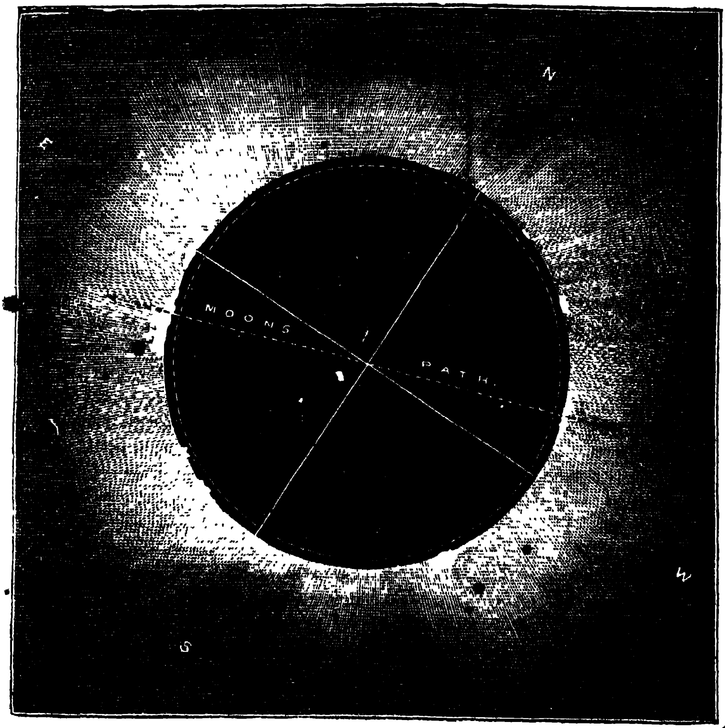
itself. Here and there, in addition to the spots, you see some portions which are brighter than the rest of the surface of the sun, or the photosphere, and these are called "faculæ." Now "faculæ" simply means "torches," *facula* being the Latin for a torch; and the people who first gave names to these things called these brighter portions "faculæ," and these dimmer portions "maculæ"; the one meaning torches, and the other meaning spots. Now I

will show you next one of these spots on a larger scale, and then you will see that a sun spot is a very wonderful thing indeed. This spot was one drawn years ago by a distinguished astonomer living in Rome, where the sky is much clearer than it is here, and therefore he was able to observe it better than we generally can, even when we have large telescopes at our disposal. Here you see is the general surface of the sun, the photosphere, and here is the spot, and you see at once that in the spot itself are different regions having different shades. I beg you to bear that in mind, because as I go on I hope I shall be able to explain to you what these shades mean. For a long time men have been endeavouring to get at the secret of these spots; and here is a drawing more than two hundred years old, which will show you that people at that time had got a very definite notion, as they thought, as to what a sun spot was. Here you see are blazing fires—torches—presenting the brighter portions of the sun; you see at once why they called them "torches"; it was because each of these flame-like portions represents a torch; and here, in these other portions of the sun's surface are darker bits, which if you were nearer you would see are intended to represent smoke; the smoke of course dimming the light of the sun which was below it.

The first great fact which was got from the study of these spots (it is a fact I am anxious to set before you, although it does not come within my lecture, properly speaking) was this—that this great sun is very much like our own earth, in so far as it rotates on an axis in exactly the same way that our earth does. Not only do the spots change their position on the face of the sun, in consequence of the sun's rotation on its axis, but they change very much from day to day and even from hour to hour; so that we have evidence not only that the sun is rotating like our earth, but that the atmosphere of the sun is subjected to most tremendous storms; storms so tremendous, in fact, that the storms on our own earth are not for one moment to be compared with them. The fact that the spots do really move with the sun, and are really indentations, saucer-like hollows (that is the next point I wish to impress upon you) in the photosphere—in that brighter portion which I have brought under your notice—is shown by the appearance which is always presented by a spot when it is near the edge of the sun. You know if you take a dinner plate and look it full in the face it is round; but if you look at it edgeways it is not round. Here are two different views of the same spot; there you look the sun spot straight in the face, and you see into it and can learn all about it; but here, where it has nearly gone round the corner and is disappearing on the sun's edge, you see it in the same way that you would see a plate looked at edgeways.

The limited time at my disposal has made my few words about the general appearance of the sun very hurried ones; but some of you will already have suggested to yourselves that I have not yet finished about the actual appearances touching the sun. You are quite right. Up to the present moment we have been dealing with what we may call the "workaday" sun, the sun as he generally appears—the sun as we know him best. But sometimes, as many of you know, the moon comes between us and the sun, and then we get what we call a "partial" eclipse of the sun; and you also know that if the moon comes right between us and the sun, all the sunlight is cut away from us, and we get what is called a "total" eclipse of the sun. Now I will show you a photograph of the sun taken by the astronomers in America, when it was partially

Fig. II.—The American Eclipse, 1869.



eclipsed in the year 1869, and you will see that the only difference between no eclipse at all and a partial eclipse of the sun is that we do not see so much of the sun as we otherwise should do. Here you see is the general surface of the sun; there is its outside edge, and here is a spot. I do not know whether all of you can see that spot—it is rather a small one—close to the edge of the sun, but you can all see that the edge is just as we usually see it. But when we get the sun totally eclipsed,—when all the sun is cut away from us,—then we see certain things which we do not see when the sun is not eclipsed and when the sun is only partially eclipsed. The importance of observing these things, and of learning all we can in the precious moments of a total eclipse, is the reason why civilized governments, whenever there is an eclipse of the sun, send out expeditions to those places where the eclipse will be seen as total. For instance, there has recently been an eclipse of the sun visible as a total one in Spain, North Africa, and Sicily, and consequently civilized governments sent out expeditions to observe the sun in those places. I will now show you exactly what I mean. On this diagram you will see parts of Spain, Africa, Italy, and Greece, and the curved lines show the regions in which the eclipse was to be seen as a total one in other places. The moon only partly covered the sun, as it did at Manchester, as you will remember, consequently we had parties in Spain, Africa, and Italy, observing the eclipse. Now let me give you some idea of what those parties saw. You see on this picture indications here and there (round the black moon, which hides the sun) of little bits of light; and at first you may wonder what they mean. Allow me to tell you. The workaday sun, when this picture was taken, was entirely covered by the moon, but strange to say, in those regions just outside the sun, where generally we see nothing whatever, are here and there, as you see, bright points of light; and here and there a sort of hazy light, which reveal to us something new. Here, in the next picture, in the same eclipse of 1869, the moon has moved a little over the sun, and those bright things that we referred to before have now changed, simply because the moon has changed her place, and because the regions near the sun which were covered before are now uncovered, so that these strange things can be revealed to us. So that you see even from these diagrams which I have already shown to you—diagrams, let me tell you, printed and warranted by the sun, for the hand of man has never touched them—these pictures, I say, show you that in those regions round the sun where the naked eye, with the un-

eclipsed sun, sees nothing whatever, there are all sorts of strange and wonderful things. Next I must tell you that these wonderful things have been seen for a very long time. And I may tell you that these wonders to which I have referred have only been half shown to you. You saw that close to the moon, where the dark moon was covering up the sun, you had here and there points of light. The reason that you had only those points of light revealed to you was not because they are not the only things which are seen round the sun during an eclipse, but because they are the brightest things, and so the photographic plate registered them sooner than it would register other fainter things outside the sun. Mr. Harrison will now show you some pictures taken in different eclipses, in which you will see that outside these brighter portions, you get other and fainter appearances further away from the sun. And I may tell you that the understanding of these things is at present almost beyond the best of us, so much do people who try to find out all about them vary, not only in the accounts they give of the things they see, but also in their explanations of what they mean. Now here is a very remarkable series of drawings, made by a very distinguished astronomer during the eclipse which happened a few years ago. Here you see, close to the body of the moon, we get a perfectly distinct ring; outside that ring we get another ring somewhat less distinct; and then, in addition to those two rings of different brightnesses, we get five rays, as seen in one picture, in one particular portion of the sun's limb or edge. Now the middle picture represents the same eclipse after the moon had travelled a little more on to the sun; and there you see that those five rays have almost disappeared, and you get some new ones in different places. Here is another picture of the same eclipse, taken by the same observer when the moon had travelled still further over the sun. There you see the rays which we first observed have almost disappeared, and a new lot of rays altogether is developed on the other side of the sun. Astronomers for a long time past have agreed to call those brighter portions which I showed you in the first diagram the solar "prominences," or "red flames;" and they form part of an envelope round the sun called the Chromosphere—that is, colour sphere—as it is in this region that the various colours are seen in eclipses, the outer rings and rays, and other strange looking things, which have been observed, have been called collectively the "corona;" so that over the workaday sun, the sun, as we see it every day, we have bright spots and dark spots

to account for; and in an eclipse of the sun we have those brighter portions close to the sun, called the "prominences," and the "chromosphere" to account for, and also the irregular ring of light and those rays extending further outside than the chromosphere itself does.

Now what I have to do to-night is to tell you just as much as I can of the manner in which spectroscopists have attempted to attack these questions, and to give you as fairly and as honestly as I can what I believe to be the conclusions they have arrived at. Now you will see in a moment that to do anything at all with the sun, separating a spot, say, from the faculæ, or separating the outside part of the sun from the middle of the sun, or the region outside the sun from the body of the sun itself, we really must no longer be satisfied with the method adopted by Kirchhoff and Bunsen, or Wollaston, and the rest of them, of dealing merely with a solar beam, but we must, literally, take the sun to bits; we must deal with here a little and there a little; we must use this magnificent instrument, the spectroscope, which, in the hands of Kirchhoff, as Professor Roscoe told you so truly and so well, has worked wonders, which has given us the largest crop of facts that we have got during this century; we must, I say, take this spectroscope, and, instead of dealing with all the light from a star, or all the light from the sun, we must take the sun to bits, and work at it little by little. The smaller the portion of the sun we deal with, the better will be the result that we shall get. Now you will see how this is to be done. Nothing is so simple. When Kirchhoff and Bunsen wished to observe the sun, they immersed their spectroscope in a beam of sunlight, in the same way as Newton did, and that gave them the light of the sun, so to speak, upon the average, as we get it when viewing the sun or a bright cloud in open daylight, making no difference between the light which comes from the outside of the sun, and the light which comes from a spot, or from a bright portion. But this method will not suffice if we wish to examine a part of the sun by means of the spectroscope. In this case we must first get a telescope to form an image of the sun, and then we must so arrange matters that the light which comes from that particular part of the sun we wish to examine shall alone enter the instrument.

We now come to the first great facts revealed to us by both these methods. The use of facts in astronomy, as in anything else, is to test our notions of things, and to help us on in the path of knowledge. Now, it so happened that our knowledge of the sun, obtained by the telescope, was tremendously upset by the discovery of Kirch-

hoff's, to which Professor Roscoe alluded. Up to the time that Kirchhoff made that wonderful experiment by means of a little sodium flame, which showed us that the sun was an incandescent, that is, a terribly hot body, surrounded by a cooler atmosphere—up to that moment, I say, the opinion of a very large number of astronomers was—as Sir William Herschel had announced in the last century—that the sun itself might be a cool, habitable globe, in which people like ourselves might live and move and have their being; that there might be beautiful fields, high mountains, cloudy skies, and the like, exactly as we have here; but Kirchhoff, with his spectroscope, said that it was nothing of the kind, that there must be a state of intense heat in the sun, and that, therefore, the sun could not be habitable. Sir William Herschel accounted for the spots, those dark regions of the sun which I have spoken to you about, by supposing that the brighter part of the sun was an atmosphere of cloud which here and there was broken open, allowing the cool, dark body of the sun itself to be seen. I need not go into details showing how he explained that that envelope which gives us all our light and heat should have been rendered rather a pleasant thing than otherwise to the people who were living below it. That is not necessary on the present occasion. But I wish to show you one important consideration connected with Kirchhoft's theory, who, by the way, held that sun spots were clouds floating in an atmosphere above the photosphere. He, as you know, wanted something solid or liquid, giving a continuous spectrum—I quote Professor Roscoe's words—and outside that he wanted an atmosphere, absorbing here a little and there a little light in the spectrum, so that the Fraunhofer lines—those dark lines which you see in the solar spectrum—should be accounted for. Now I think I am not going beyond the mark when I say that Kirchhoff himself, and all those who followed him, came to the conclusion that the real atmosphere of the sun was the Corona which I have just shown you on the screen, as revealed to us during an eclipse. You know that it must have been a comparatively cool atmosphere because it was essential that the atmosphere should be cooler than the underlying substance, or else you would not have the Fraunhofer lines at all. All that has been thoroughly explained, and I need not go into it.

But let me now show you how admirably the new method of taking the sun to bits enables us to settle the question once and for all by a single observation. As I told you, Sir William Herschel came to the conclusion that a sun spot was

really a hole in the sun's clouds, which enabled us to see the dark body of the sun. Now that was entirely exploded by Kirchhoff's discovery. But after Kirchhoff's discovery there were two reasons given to account for a sun spot which you will see do not at all agree with each other, or with the explanation given by Kirchhoff himself. A distinguished Frenchman, Monsieur Faye said that a sun spot was seen by us as a sun spot because there we lost the light from the outer envelope of the sun, and got but a feeble radiation from the intensely glowing interior gases of the sun; whereas English observers, and among them Dr. Stewart, a townsman of yours, gave very good reasons why this could not be so, and held that a sun spot was black because the light and heat, which the sun must be giving out there, as everywhere else, had been gobbled up, so to speak, before it got to us, so that it came with a balance on the wrong side of the account. Now let me show you on the screen the sort of thing which we have as the representative of the new language of the spectroscope as applied to taking the sun to bits. In this case we are looking at the orange portion of the spectrum of a sun spot. I am afraid that this will require some little explanation, but if you will bear with me one moment I think I shall be able to make it clear to you. You all know what that wonderful double line D means; it is the absorption line of sodium seen in the solar spectrum. Now here is the double line D, as seen in a spot spectrum; and I beg you to observe that along the spectrum we have a shade, showing that the spectrum there is enfeebled all along its length; and if the screen were large enough for me to have a diagram giving you the spectrum as seen from the red to the extreme violet, you would find that you would get that general enfeeblement all along. In addition to the general enfeeblement of the light, you get a wonderful thickening out of this classical double line D. There, you see, it widens out gradually; there it widens out suddenly.

Now what does all this mean? Allow me to recapitulate what has been told you before, that solid, liquid, and densely gaseous or vaporous bodies give us a *continuous* spectrum. Let me show you what I mean by a continuous spectrum. Mr. Harrison will now be good enough to throw on the screen a spectrum, which I am sure most of you will recognise as the beautiful spectrum which you have seen before in the rainbow. I may tell you that the great point I wish to bring before your notice, in the first instance, is that the spectrum is complete from red to the extreme limit of the violet. As you see it on the screen, nothing could

be more beautiful I am sure you will all acknowledge. Here, then, we have what is called the "continuous" spectrum; that is to say, there is no leaving off of the light; there are no gaps. Now that is the sort of light we get from a solid, or a liquid, or a densely gaseous or vapoury substance, whatever it is; whether it is a match; whether it is the interior of the sun; whether it is coal, iron, steel, mercury—anything—we get that same sort of spectrum; and as long as we have that sort of spectrum, we do not know what the particular substance is that gives it, we only know that it is a solid, or a liquid, or a densely gaseous or vaporous substance. But if we deal with a gas or a vapour we get something perfectly different. You see at once that the moment the slit is narrowed, and we begin to deal with the gases and vapours which are in that lamp, that we alter the continuous spectrum entirely, and get a discontinuous or broken one.

Now I want you to be kind enough to allow me to define four important things. The giving out of light by such an arrangement as Mr. Harrison has in that lamp, is called the *radiation* of light. I want you to allow me to call that *general* giving out of light "general radiation;" and I want you to let me call that giving out of light such as you see now *discontinuous*, and I thank Mr. Harrison for enabling us to see these things so well. I say I will call that "selective radiation." So that the giving out of light may be of two kinds, general in the case of solids, liquids, or dense gases or vapours; and selective if we are dealing with gases or vapours which are not dense. So much for the giving out of light, or radiation,—all this by way of reminder. Now I want to deal not only with the giving out of light, but by the stopping of light; and I will tell you exactly what Mr. Harrison has done. He has been good enough to smoke a piece of glass, and he will stop the light as well as he can by means of that piece of smoked glass. Now I think all of you can see that wherever that glass has been smoked, we get the light passing through it eaten out all along the spectrum. In fact, the stopping of the light here is as general as the giving out of light was in the first case, so that we match general radiation by general absorption. Now if Mr. Harrison would be good enough, instead of using smoked glass, to give us such a substance as red glass, or any similar substance which we know has a peculiar action upon light, you will see something very different at once. There is red glass. You see that now we have not to deal with what we had to deal with before in the case of smoked glass; we have not to deal with something which stops out all the light equally, but we have to deal with something which stops out

all the light except the red, exactly as in radiation we had to deal with things which gave out a line here and there, and did not give us light all over the spectrum. This not only shows why red glass is red glass, because it allows the red kind of light to pass, but it shows that we have general and selective radiation balanced by general and selective absorption. Here again you see absorption due, not to red glass, as before, but to a different substance altogether—to chlorophyll. And now it is the green part of the spectrum which is alone left, and not the red. So that when we send light through bodies we have a kind of action which is exactly similar to the kind of action which we get when we have light coming to us from brilliantly incandescent bodies. Now you will see, in the first place, in this picture of the spectrum of a spot, that we have no indication, first of all, of bright lines. This is a faithful copy of nature, and you see there are no bright lines at all. Here, then, is a single observation, disposing for ever of the French idea that a spot was due to the radiation from an intensely heated interior solar gas. I do not know whether I have made myself quite clear. But now let us see how it bears on Dr. Stewart's idea. These horizontal bands which you see here are, as you will understand in a moment, indications of general absorption. The general absorption is, no doubt, due to dense gases or dense vapours, which, as I have just told you, if they were intensely radiating, would give us a continuous spectrum. Get a dense gas, make it incandescent, and its radiation is continuous. Get a dense gas as you have it on the screen, and instead of radiating make it absorb the light, put it between you and a substance which is radiating, and its absorption will be continuous. So that so far as these horizontal bands go, they show you we have to deal with absorption due to dense gases or vapours. There is some dense gas or vapour which is cutting off from us the sun's light where a spot is, and that is one reason that the spot is dark. That is the plain English of the thing. But that is not all. I will now draw your attention to that thickening of the sodium lines. I shall show you, by and by, that that thickening of the sodium lines not only enables us to say that the sun spot is dark because there is some dense vapours there, but it enables us further to say that the sun spot is dark because among those vapours is sodium vapour. I might parallel that in the case of other lines in the solar spectrum, but I have taken the case of sodium as sufficient for my purpose for the present. Now there is another very curious fact which I beg your attention to in connection with what I have

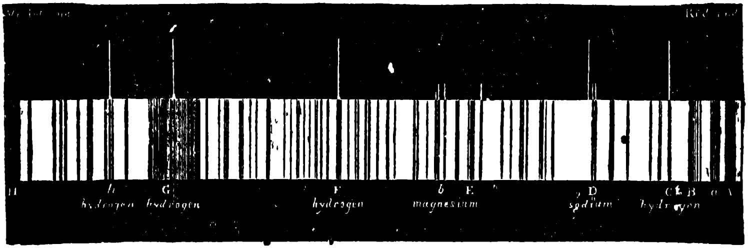
said; and I hope have been clear, because it is important that you should get this thoroughly into your minds. If we observe the spectrum of the faculæ, instead of observing the spectrum of the spots—that is to say, if we observe the spectrum of the brightest bit of sun that we can find, instead of the blackest bit of sun we can find, we shall discover that that bit of sun is brighter, for two reasons; first, there is no absorption at all of the general kind, no absorption stretching along the spectrum in that horizontal way which you see there; and, secondly, all the lines which are thickened in a spot are thinner in a facula.

And now I come to a part of my subject which probably may startle you, if you are not already familiar with it. I have shown you that there are a good many things round the sun which we do not see except the sun is eclipsed; and you will take it for granted, I dare say, that the new method of taking the sun to bits, as I have called it for simplicity's sake, has nothing whatever to do with those things which we see outside the sun during an eclipse. Nothing of the kind. The spectroscope has a good deal to say to those things, too; and you will say how? Well, I will tell you. What is the reason that we don't see these things except during an eclipse? Because the region of our atmosphere near the sun's place is lighted up by the sun so brightly that we cannot see them, any more than we can see the stars, but we know that the stars are there, and we know that these things round the sun are there, for night comes and we see the stars, and now and then the kind moon comes and cuts off the sunlight, and then we can see the things round the sun. But the spectroscope very fortunately does come to our assistance, if, for one moment, we are willing to agree that those things round the sun are not liquid, solid, or densely gaseous, but are built up of gases or vapours, which are so little dense that they can give us bright lines. And for this reason. If we get the spectrum of a solid, that continuous spectrum which you have already seen most beautifully represented to you upon the screen, we can, by adding prism after prism, prism after prism, make that spectrum so dim that you can hardly see it at all. We might say that, in the case of the continuous spectrum, nature is prodigal of her light, she spreads it all over the place, and by spreading, weakens it. But now, mark what happens if, instead of a continuous spectrum, we have what I have ventured to call the selective spectrum, the spectrum, for instance. of which all the light consists of one, two, or three lines. Then, in that ease, by adding on prisms, we do not spread that light—it is still one, two, or three lines, however many prisms

we use, and it is not spread all over the place in the same way that the continuous spectrum is, which you saw was complete along the spectrum from red to the extreme limits of the violet. So that you see in an eclipse we have the moon cutting off the light which hides these solar appendages from us except during an eclipse, and we have the spectroscope, armed with a large number of prisms, doing exactly the same thing; it kills the atmospheric light in one case, and the moon does not allow the atmosphere to be lit up in the other. So that in either case, whether the sun is eclipsed, or whether we use a powerful spectroscope, we should see these things round the sun if we assume that they are built up of gases or vapours. I will show you the instrument by which it has been attempted to artificially eclipse the sun in this way, and I think you will see in a moment how the thing works. Here you see is such a system of prisms as I have just mentioned to you. Here is the slit of the spectroscope, and through this aperture in the eye end of the telescope the image of the sun is thrown into the slit. The light is taken up by that instrument which you see there, and it is brought round and turned, and twisted through all these seven prisms, till it ties a true lover's knot, and comes back again, crossing its own path, and is driven down to the eye of the observer. So that instead of having one or two prisms, as Mr. Harrison has in his arrangement, we have no less than seven prisms to disperse the atmospheric light. And, as a matter of fact, I can tell you that the action of the prisms is so satisfactory that no atmospheric light whatever gets through that instrument to the eye when the sky is perfectly clear. Well, then, you will ask, How about the things round the sun? Well, the things round the sun are easily visible in that instrument. Let me show you how they appear to us. I must, however, tell you that this observation of the prominences without an eclipse was first made by Dr. Janssen the day after the eclipse which was observed in India, in the year 1868. Let me show you now the sort of thing that we get by this new method, and by using this large dispersion. You must imagine that here is the slit of the spectroscope, so arranged that half the sun's image falls on the slit, and half of the slit falls off the image. So that here we have the spectrum of the extreme edge of the sun; and here we have whatever we can get outside the sun. Now what have we got? There is one of the lines which we always see around the sun by this new method of taking the sun to bits; and I need not tell you that it is one of the lines due

Fig, III.—Spectrum of the Sun and Chromosphere.

1.—Spectrum of the Cromosphere. 2.—Spectrum of the Sun's Edge.



to hydrogen; because in what has been told you about the solar spectrum you have heard that the line C (and this is nothing but the line C in the solar spectrum—in the red end of the spectrum) is due to the absorption of the hydrogen. Nothing you see could be more beautiful than the absolute proof afforded by this of the accuracy of everything which Kirchhoff and others had predicted with regard to the reasons for the lines. It was impossible in the then state of science for them to put the sun and the hydrogen absolutely in the same instrument in the way it is done here; but here you see the hydrogen of the sun absolutely where there is no hot sun behind it, giving you the bright line, and also in those regions where there is a hot sun behind it, or, I should say, a hotter sun behind it, giving you a dark line. If I had time I could show you the other hydrogen lines which are seen by this new method. I think, however, you will now at once appreciate with what justice those who first named those strange things round the sun "red prominences" and "red flames," came to their conclusions with regard to colour; although that is not so easy as it seems, seeing that prominences have been seen of almost every colour of the rainbow; and that is a fact which I hope I shall be able to explain to you, if time does not run away too quickly. I want now to show you the red tinge of the gas in this tube. I do not know whether you can see it plainly, but if it were possible to show this gas under proper conditions, you would see not only that the gas in the tube is itself red, but that the spectrum which we get from the hydrogen in this tube is exactly the same as the spectrum which we get from the hydrogen in the sun. I do not know that it would be possible to have a more convincing proof of the truth of what Kirchhoff has told us with regard to the sun on this point. Assuming,

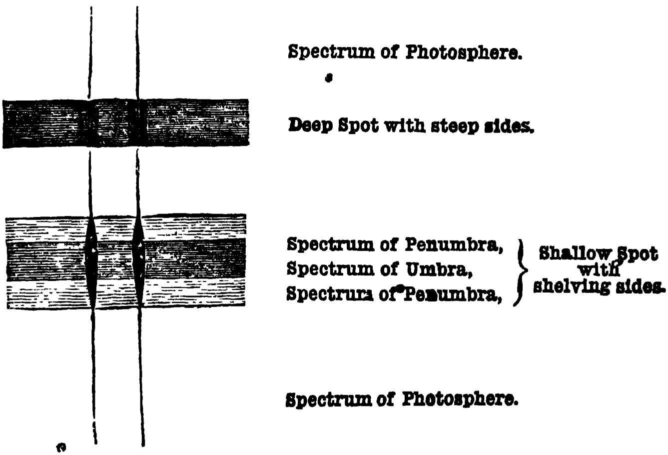
then, that we have hydrogen generally round the sun, and that it is always present, let me tell you what next happens. Into this hydrogen are injected in the most beautiful order whenever there is a storm, underlying vapours, the bright lines of which vapours we generally see thickened in the spots. I hope you follow that. We take for granted, on telescopic evidence, that the spot is a cavity. We assume, then, that the spot is a place filled with these denser vapours which I showed you on the screen were indicated, in the first instance, by that general absorption, and then again by that selective absorption in the case of sodium vapour; and I told you that it was possible to multiply these cases in the matter of other things besides sodium; and then you see going up outside the sun, when there is any great state of disturbance, exactly these substances the lines of which are thickened in the spot spectrum; only when these substances come up, then these lines are thin. Now, what does all this mean—this thickening out of the line in some cases, and the thinning out of the line in others. I dare say it may seem to some of you a ridiculous distinction to draw. Surely, having got the Fraunhofer lines, and having settled to a very large extent what they all mean, it is rather hard upon them to chide them when they are thick and chide them when they are thin. If you will bear with me for one moment I shall be able to show that we were completely justified in not resting content with these thickenings and these thinnings without trying, if possible, to understand something about them. And I may tell you that I think if anybody had time, and would, for the next ten or twenty years, employ that time in observing the spectra, and determining the different thickening and thinning of these lines, he would do as much for science as any man could do in that period. You know what an immense thing was done when it was determined that by showing a line here and a line there in the spectrum you could determine the existence of a much smaller portion of the substance that was indicated by that line than you could by any other method. Now, in addition to the fact of these constant lines being given out by the same substance, it has long been known to those who have studied the question more deeply that the same substance is competent to give us different kinds of spectra; that is to say, that although the spectra in some cases have a general likeness here and there, you do get a very marked distinction between the spectrum which you get of the same thing as seen under one condition and as seen under another. You may ask me to tell you what that condition is. Well, I must tell you that up to a little time ago, if

even not at the present moment, doctors differ. These gases are observed in tubes something like this which you see on the table. What we do is to get the electric spark, as we have here; we then make it pass through a gas enclosed in tubes, as you see here, and then we observe the spectra entitled light. If we get a change in the spectrum of the gas or vapour, it is difficult first of all to find out to what that change is due, whether it is due to increased temperature,—as we have power to vary the temperature—or whether it is due to difference of pressure. Some people think one thing; some people think another; but two workers in England have lately come to the conclusion that temperature *per se* has very little indeed to do with these changes of spectra, except to render the spectra, when they exist, more visible, and enable us to observe them better; but that pressure, which is tied up with the density of the gas or vapour, has really very much indeed to do with it. Now some of you may have said to yourselves, I wonder whether this pressure has anything to do with the thickening and thinning of these lines? Well, it has everything to do with it. Fortunately in the spectrum of hydrogen, which I have told you exists in these prominences; in the spectrum of sodium which you all know exists in the sun; and in the spectrum of magnesium, we have lines which really seem to have been placed in those spectra by nature, that we might study these rings round the sun to better advantage than we should have been able to do without those lines. There is a line in each of these spectra which thickens out in a most remarkable and beautiful way; and we have shown, I think, beyond all doubt, that the widening out of these lines is really due to pressure. Now I do not know whether I shall be able to show you this on the screen. I will try; but you must bear with us if we do not succeed; it is avery difficult thing to do; but if I succeed I think you will say it is worth while to make the trial. Now there is one way, a very delicate way, in which it is possible you may see it; but more wise than some people, we have our reserves; and if this first experiment does not succeed we will bring up our reserves, which I think will help us. Let me tell you exactly what Mr. Harrison is good enough to attempt to do for us. We have some metallic sodium enclosed in that lamp, and we are going, first of all, if possible, to give its spectrum by means of a strong current due to forty of these electric elements which are in this part of the room. Now with a given amount of temperature you will get a certain thickness of line. What I want you to see is, that with a varying temperature

you will get a varying thickness. I think you see now that you get a much thicker double line than before. [Dr. ROSCOE asked for the experiment to be repeated.] We will repeat that experiment once more, as it has succeeded. You see that the line thickens. Now you may think that this is a proof that I was wrong; that it is not pressure, that it is not density at all, but that it is temperature. We have an arrangement here which I think will put that beyond question. Let me explain what that arrangement is. We have some metallic sodium in this case—not the source of radiation; we do not use the sodium in the lamp, and examine the radiation from its vapour; but we deal now with the absorption of the vapour. Now, as according to the change of pressure we get a thickening of the bright sodium line; we ought equally to get a thickening of the sodium line, when instead of sending us its light radiating to us, it really is absorbing that light: because, as you have heard in the previous lecture, according to the theory of exchanges, the absorption and radiation are always equal. What we shall do in this case will be to heat the metallic sodium very slightly in that tube, and as we heat it you will see that the vapour will be perpetually given off by the metallic sodium, so that near the lump of sodium at the bottom, the cloud, so to speak, of sodium vapour will be denser than higher up away from the metallic sodium. I must tell you that as we have the lens there, the line will appear to be upside down on the screen. What I expect we shall get will be a dark line, somewhere near where you see that yellow line at present; and I hope you will see that the thickness of the line will be greater at bottom than it is at the top; and you have the appearance of things reversed by the lens. We have now the radiation of sodium as you saw indicated by that yellow line. We shall hope to exchange the radiation from the sodium, which still exists in the lamp, for the absorption of the sodium vapour which Professor Roscoe is so good as to heat in that tube; and if we succeed, you will see a dark line in the place: thick where the sodium cloud is thick, thin where it is thin, although the temperature is the same. Hence, then, it is not temperature which causes the variation. But whether the experiment succeeds or not, observations made upon the sun itself, put the question, I think, beyond all doubt. You will acknowledge that if it were a question of temperature merely, the hot prominences that gave bright lines on the sun should give us thicker lines than the cool absorbing clouds. Therefore, if we get sodium prominences on the sun, we ought to have the

sodium lines thicker than we have them in a spot. Now here is a case in which over the very thick lines of sodium, as seen in a spot (I think you will recognise these horizontal lines again, and this thickening of the sodium line), we actually have an extremely bright and very thin sodium line, showing, according to our idea, that at a high region in the sun's atmosphere you had a cloud of sodium vapour hotter than anything behind it, giving you an indication of the prominence over the region where below it the cooler sodium vapour is indicated by extremely thick absorption lines. So that we have this new method settling for

Fig 3 A.—The Thickening of the D line is the Spectrum Spots.



us what a spot is, and what a facula is. We have this new method settling for us what are those strange red flames seen round the sun during an eclipse, and we have it telling us something about the pressure at work in the chromosphere. I might go on and tell you more about what the spectroscope enables us to determine with regard to these outer envelopes of the sun which are only seen during eclipses. I refer to the corona, which your townsman, Mr. Brothers, has been so extremely fortunate in photographing in Sicily during the last eclipse. But I reserve what I have to say about that for the extreme end of

my lecture. I hope you are not tired. I have not quite finished. I should like to tell you that by this new method the forms of the prominences are seen as well as those cypher bands, those hieroglyphics by which we can determine their nature; so that by means of a prism, or a combination of prisms, we may first turn our instrument on to the prominences, or on to a part of the sun even outside the prominences, and first say what they are made of, and then, after that, by a certain arrangement of oscillating or revolving slits, &c., or even by means of opening the slit, without the use of any absorbing medium whatever, it is perfectly easy, after we have found out what the sun is made of, to look at it, and see exactly what it is like. I am sorry to say that in coming from London part of our apparatus got broken, which would have shown this. Mr. Heywood will now be good enough to throw upon the screen two pictures of some prominences seen by this new method of merely opening the slit. It shows you the enormous changes which go on in these prominences. Of course, as long as we are dealing with merely their chemical nature, we cannot examine much into their form; and, therefore, it is somewhat difficult, although it is not impossible, to determine the amount of change. But, when we have settled the chemical nature of any particular prominence on the sun, we can not only determine its form, but we can determine its rate of change. Mr. Harrison will show you the changes that take place in the prominences nearly 27,000 miles high, in the space of 10 minutes, and I think you will acknowledge that, in the changes indicated by that picture on the screen, we get an idea of force and a conception of vastness which it is impossible to become acquainted with by anything that we can study on this earth. And this brings me to another part of my story altogether, one that would have required considerable time to enlarge upon, had I not been able to refer you to Mr. Huggins's lecture, as I was able to refer to Professor Roscoe's lecture for the basis of solar chemistry. Mr. Huggins showed you that by means of alterations in wave length, he was enabled to say that a certain star was receding from the earth at a certain rate; and, if I recollect, he instanced the case of a swimmer who is swimming with the waves, as against a swimmer who is swimming against the waves. When a man is swimming against the waves he meets and has to surmount very many more waves than he would have to do if he was swimming with the waves. You may imagine the earth to be a swimmer, and you may imagine the different heavenly bodies to be the source of different waves which come to the earth,

the swimmer, and which the earth has to make the most of. If those waves (in our case they are waves of light) are receding, if the body which is paying out those waves, as a telegraph ship pays out a cable, is going away from us, then you will see at once that it will be equivalent to stretching those waves, that those waves will be longer; but if we meet those waves and have to breast them, you at once see that they must be shortened. That, if I recollect, was the line of Mr. Huggins's argument, and the result was that he explained to you with considerable clearness that in the case of a planet, or of any celestial body which gives light, if it is approaching the earth, on which we dwell, with any considerable velocity, there will be an alteration in the length of the light waves, and that alteration in those waves will be determined and determinable only if in the spectroscope the spectrum of that body gives us lines. Now you know that in the case of the solar spectrum it is full of dark lines from one end to the other; and in the same way sometimes round the sun the spectrum of bright lines which we see, instead of the spectrum of hydrogen simply, is more or less complete from one end of the gamut to the other. But you will say, it is all very well for Mr. Huggins to measure the velocity of a star with reference to the earth's motion by saying that a particular alteration of wave length has taken place in any particular part of the spectrum; but how are you going to work that in connection with the sun? Well, allow me to show you. You see we are in presence of a new thing altogether, and this new thing would be explained if you accept the fact that on the sun there are these different gases and vapours that I have spoken to you about, which in the case of the prominences change tremendously in the space of ten minutes, and in the case of spots change from hour to hour; I say you will understand it if you recollect that tremendous changes are taking place on the sun, changes so enormous in fact that they are comparable to the velocity of light, and that we get just as clearly an alteration of wave length due to these changes on the sun as we do from the actual translation of a star from one region of space to another. Now let me explain to you this diagram. This line which you see is the dark line C in some cases, and in other cases, as here, the dark line F in the solar spectrum; it is, therefore, an old friend of yours; you are quite familiar with it. But you will see at once that the moment we get off the sun itself, we get something perfectly new; the line instead of being an upright fellow, as it is there, is twisted and turned in all sorts of ways. Now the explanation which has been given of these very strange contortions is that, in this case, the

line indicating hydrogen is thrown out of its proper place in the spectrum, and has got into the region of longer waves; that the wave, as it were, is stretched, and, therefore, that it appears in a part of the spectrum, where the longer waves generally live; and here where you see it twisted, not to the left, as in that case, but to the right, it has travelled towards the region of shorter waves because its wave has been shortened. Now what do these two assertions mean? They mean that in that case, which I have indicated, that part of the solar prominence is lengthening out its waves; in other words, that it is going away from us; and that in this part of the prominence, in consequence probably of a sort of spiral motion, it is rapidly coming to us, as rapidly as that is retreating from us; and by carefully measuring the distance to which these various changes and contortions go (you see that they vary in every one of these diagrams) we can determine not only the fact that a portion of the prominence is coming to us or going away from us, but we can actually determine the velocity with which it is going away from us or coming towards us, because the Fraunhofer lines can be really used as so many milestones. In this way we have been able to determine the existence of tremendous cyclones on the sun, or wind-storms you may call them if you like, exceeding anything that we can imagine here. We can watch the wind travelling along the sun at the rate of 120 miles a second; we can watch the different portions of the solar envelope torn up and carried high into the solar air at the rate of 40 miles a second—40 miles a second, not 40 miles an hour—and in this way we have been enabled to show not only that there are tremendous storms and wind currents there, but that they are the same sort of currents which you get in a tea-kettle, going far down into the sun—much further down into the sun than we know anything about—

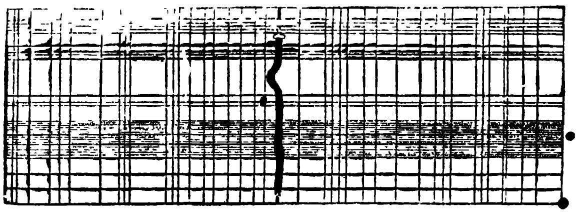
Fig. IV.

Showing changes of wave length in the bright line seen in the Chromosphere

and right to the outer portions where in our spectroscopes we can study all about them, and measure with considerable accuracy their velocity and their change by this new method of taking the sun to bits. Here are five patches of light which at first look extremely strange, but I am certain that a large portion of my audience know exactly what these five points of light mean; but, all the same, a little explanation may be of value. This is the F line of the sun. Here we have not only indications of general absorption—which means that we are dealing with dense vapours—but we have a wonderful shading off of the dark absorption line

Fig. V.

Showing changes of wave length in the F. line on the Sun and near Spots.



towards the red end of the spectrum; in other words, the hydrogen represented here by the F line was travelling rapidly towards the region of long waves, and therefore away from us—in fact it was going down, down, down into the spot; while here we see the hydrogen, intensely bright and hot, coming up, and you see that that lies to the right of the F line, towards the region of the violet—the region of shorter waves—and therefore we know that in this spot we have hydrogen coming up at the rate of something like 30 miles a second, quite hot, incandescent to the last degree; and a little way off there was a current of a cooler hydrogen going down, so as to keep up the balance in that region of the sun. Now here you have a small spot in which you get an up-rush of heated hydrogen, as is indicated by that patch of white, and by it lying, moreover, to the right hand of the spectrum. But here, instead of going down, as it did there, what does it do? It heats the neighbouring hydrogen, renders the hydrogen in that region not hotter than the sun underneath, but just as hot; it parts with all its spare heat; and you see that the Fraunhofer line, which we thought such a constant thing, has disappeared altogether; and the reason you get no indication of hydrogen there, either as absorbing or radiating, is that the hydrogen is of exactly the same temperature as the things below

it, and that, therefore, it both radiates and absorbs; and, therefore, so far as we were concerned, if we knew nothing else, it would be just as non-existent as it is in those stars where the spectrum of hydrogen is not visible, although we know pretty surely that hydrogen must be there.

So much, then, for the outcome of this new method of taking the sun to bits. We have observed the spots; we have observed the region outside the sun; we can not only determine what it is made of, but we can determine what it is like; we can observe its changes, and we can measure the velocity with which the different currents are moving there almost as accurately as we can observe the currents on the earth.

Now I had a great deal more to say, but I am sorry to say that my time is altogether gone; and if you will allow me, I will conclude my discourse by showing you two photographs taken by Mr. Brothers, your townsman, at the recent solar eclipse in Sicily. I am particularly anxious to show you these pictures which have been taken by Mr. Brothers, because they are certainly the most important contribution which we have had for some time with reference to our knowledge of the outer part of the solar envelope, as a region is photographed in them which has not been photographed before. Recollect that at present our knowledge with regard to the sun may be stated to be as follows:—We know a little about the spots; we know a little about the outer rim, that outer bright portion which is called the photosphere or light sphere, which I very early introduced to your notice. Underneath that I think we know absolutely nothing whatever; and the more a man talks to you about what is inside the sun, if you will take my advice, the less you will believe in him. Also with regard to the outer portions of the sun, what lies outside, what is the exact meaning of those strange rings which I showed you, I beg you even in that case not to place too much reliance upon very certain statements. I do not think the thing is certain either one way or the other; but the man of science, the man who is anxious for truth can always afford to wait; and I think we can afford to wait in this case; and I hope that you won't go away from this hall to-night imagining that either you or anybody else knows all about the sun. We don't; we only know very little about it, and that little is confined to a very limited region. We don't know exactly what is outside the sun; we don't know what is inside; but if we fix upon the outside of the sun, as we see it generally, and work gradually (it may be a work of years, of decades, of centuri[illegible]rhaps) first looking outside, then a little lower

in, and so on, in the long run we shall obtain a sure and certain knowledge. But these photographs of Mr. Brothers's will certainly have to be taken into consideration by those who are certain about these matters, either one way or the other. I may tell you that this outer portion of the sun, which you see here, is undoubtedly a portion of the gases or vapours which lie outside the photosphere, and outside the prominences, which are too faint to be picked up by this new method of taking the sun to bits. Here the light which we lose by our great dispersion is so great that it is greater than the special light which is emitted by this portion of the sun; and, therefore, we can only see it during eclipses. But there is no doubt whatever about a portion of what you see there absolutely belonging to the sun, and I do not suppose that anybody who has ever studied the sun at all, or has even read anything about the sun, and about what has been done with respect to solar matters for the last 50 years, can doubt the thing for a moment. But here Mr. Brothers, you see, in these very exquisite photographs, makes the sun altogether bigger, than what we had before. Now the question is—a question which I shall not attempt to decide either one way or the other—does all that belong to the sun, or does it not? About the inner portion there can be no doubt whatever. About the outer portion, however, there is still some doubt. But I think we may fairly be content, after all, not to attempt to settle this thing in too great a hurry. We have waited, now, I don't know how many thousand years, before we knew so much about the corona as we learned on a certain day the month before last; and it is not well for us to hope to settle the enormous field of research in a few seconds. But whether we have longer to wait or not, I think you will all agree with me that anything which increases our knowledge of the sun—which increases our knowledge of that luminary which gives us light, which gives us heat, which gives us, we may say, our life; which is the centre of all our force; which is the origin of all our work, either by the bottled-up energy of the sun, as represented by coal, or by the bottled-up energy in our veins is a thing entirely to be desired, and I think you must acknowledge that, although astronomers have been twitted for going in, as it has been said, too much for that hydrogen in the sun business, still I think that it can do nothing worse than ennoble us, and make us lift our minds from our workaday matters to higher things, when we attempt to solve those riddles which the united work of all the men who preceded us has been powerless to effect.

Dr. Roscoe called upon Mr. Brothers to propose a vote of thanks to Mr. Lockyer for his learned lecture. Mr. Brothers supplied a modest omission of Mr. Lockyer's by mentioning that that gentleman announced the independent discovery by himself of the red lines of the prominences before the French astronomer whom the lecturer had credited with the discovery. To Mr. Lockyer we are also indebted for inducing our Government to send out the late eclipse expedition.

Dr. Roscoe made an interesting statement respecting the origin and support of these Science Lectures for the People, and mentioned that the considerable deficiency in the funds had been generously supplied by Mr. T. J. P. Jodrell.

Alderman Rumney proposed that their thanks should be given also to Dr. Roscoe, upon whom had devolved the chief part of the labour connected with this valuable course of lectures; and also to Mr. Jodrell.—Both propositions were heartily received and passed with acclamation.

Mr. Lockyer, in acknowledging the vote of thanks, congratulated the people of Manchester in having such scientific gentlemen as Dr. Roscoe and Dr. Stewart in their midst, and added a few appropriate remarks on the duty as well as the pleasure of communicating knowledge.